PRODUCT ENGINEERING

APRIL, 1943

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PRODUCT ENGINEERING

VOLUME XIV APRIL, 1943 NUMBER 4

IN THIS ISSUE

Signal Corps Communications

Success of the United Nations in World War II depends largely upon the effectiveness of the communications systems and devices that are used by the various administrative, command, and combat units for the rapid transmission and reception of strategic information. It is the job of the Signal Corps to develop, procure and install the equipment for getting the message through. In the performance of this vital assignment many strange devices in the fields of radio, wire-telephony and telegraph, by means of which information can be flashed to men traveling in mechanized units or in fast flying aircraft, have been developed. The lead article, beginning on page 195, tells some of the story of how the work of the Signal Corps has advanced since the days of smoke signals and wig-wagging.

Shrink-Fit Tolerances

When a friction grip is to hold mating female and male parts, shrink fits may be used for metal-to-metal contacts. This fit, which may be secured by one of three methods, depends upon a proper negative clearance based upon empirical design. For the tolerances allowed by leading companies, and the methods of making the shrink fits, see page 214.

Self-Cooled Journal Bearings

Busy engineers will appreciate the direct approach and procedure for calculating oil temperature, load capacity, film thickness and other design characteristics of self-cooled journal bearings, as set forth in the article "Heat Conditions Govern Design of Self-Cooled Journal Bearings," page 231, by Professor Merhyle F. Spotts. The author's method is based on the premise that, at stabilized operating conditions, the heat produced in a bearing is lost at an equal rate

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through the housing by means of convection and radiation. Included also is a brief resumé of the subject of viscosity, Newton's Law and Petroff's Bearing Equation. The charts shown on pages 253 and 254 supplement the article.

Aluminum Parts Design

Design of castings and forgings in aluminum differs in some respects with design practice for iron and steel castings and forgings. Best results with aluminum may be obtained by following the recommendations on pages 234 and 235 for thicknesses of sections, beading, and junctures in aluminum alloy parts.

Designing Die-Castings

Factors to follow when designing die-castings are presented on page 237. In this article, the first of three installments, the author, Herbert Chase, compares the composition and properties of alloys used in die-castings. Much of the information is presented in tabular form.

Keys and Keyways

Merits and disadvantages of various types of keys and keyways are discussed by Arthur H. Korn on pages 242 and 243. A key that is becoming more popular in the machine tool and automotive industries since it is inexpensive and easy to produce, is the Woodruff key. Information is given on the use of Woodruff cutters for cutting parallel keyways for various shaft diameters.

Thermosetting Series Covers Wide Range

Numerous formulations comprise a new series of synthetic thermosetting resins, which have interesting possibilities, and which were developed by the Columbia Chemical Division of the Pittsburgh Plate Glass Company. Variations in properties of the different formulations are made by adjusting the chemical structure of the molecules of the monomer, rather than adding plasticizers. Commercial development is being centered on the 39th variation of this series because its general properties are believed to be widest in demand. A discussion of these resins, with emphasis on the properties of C.R. 39, begins on page 223. Forming and machining characteristics and limitations are covered and testing techniques are described.

Vacuum Cup Locks Hold Splines on Vertical Lofting Board

Efforts of the Fleetwings, Inc., lofting department to solve a tight space problem resulted in the use of vertical lofting. But standard lead ducks could be used only on horizontal boards. Therefore, a suitable device for holding splines on vertical lofting boards had to be found. The answer, described on page 222, proved to be a modification of the vacuum-cup coat hanger for use on automobile windows. In solving the problem, however, considerable money was saved and availability was improved.

Buckling Strains in Compression Loaded Panels

Realizing that engineers do not have the time nor the desire, because of the complex mathematics involved, to acquaint themselves with exact methods for predicting the occurrence of permanent buckling strains in thin flat panels which are to be loaded in compression, F. N. Platt, structural design engineer at Fleetwings, presents in this article, page 211, an approximate method for determining the deflection at which permanent buckling occurs.

Kolene

Considerable attention is being given a new cleaning process by which it is possible to "tin" cast iron and alloys that have heretofore resisted "tinning." Application of the process, described on page 228, to the bonding of high lead babbitts to cast iron conserves tin and eliminates the necessity for anchor holes or grooves in cast iron bearing shells. Other applications are also being investigated.

Solving Equations By Trial and Error

How the unknown in higher-degree equations can be found through a trial-and-error method is described by H. A. Bolz, associate professor of machine design at Purdue University, in the article on page 217. Solutions of first degree equations do not offer much difficulty to the average engineer, but it is a different story when it comes to finding the roots of higher-degree equations. Professor Bolz's method may save someone several headaches.

Sintered Powdered Metals For Brakes and Clutches

Problems in designing clutches and brakes having facings made of sintered powdered metals are discussed at length by engineers of a firm devoted almost exclusively to the development and manufacture of such facings. The article, beginning on page 218, covers many forms in which this type of facing is now used, possibilities of variation in composition, and smooth load handling characteristics in extreme ranges of size and capacity.

WHAT'S COMING

German War Equipment Design

Design of German ordnance, trucks, jeeps, tanks and machine guns will be comprehensively described in both words and illustrations in the next issue. Uses of powdered-metal pressings and redesign of the German version of the "tommy" gun, anti-aircraft guns and plastic gun stocks are included. The material for this article is based on captured enemy equipment.

Measuring Impact Loads

An extremely simple method for determining impact loads experimentally, despite the fact that most design problems requiring the determination of impact loads cannot be solved mathematically because of the complexities involved, will be described in the next issue by L. D. Hagenbook, chief engineer of the Goodman Manufacturing Company. No complicated test apparatus is required. The familiar Brinnel testing technique is employed.

What to Put in a Title Block

What goes into title blocks on drawings will be reviewed next month. Sample title blocks from about a dozen concerns will be presented and an analysis made of each one from the standpoint of each company's problems. Change notices, bills of material and approvals are to be covered. No attempt will be made to pass judgment on the various practices since they are intended merely to show what some companies are doing.

Food—The Deciding Issue

Our food problem remains to be solved

THE first thing the Germans did when they occupied Czecho-Slovakia, Poland, Belgium, France—was to empty all warehouses. Everything went into trucks headed for Germany.

The Nazis knew that this war would be won by the army that had the most supplies and the best supply system.

The Nazis knew that supplies are as essential as guns. They knew that the most essential of all supplies is... food.

Being the only people on earth who can watch women and children starve, the Nazis seized upon food as their most powerful instrument for disciplining the masses. They added famine to their arsenal of conquest.

The flocks and herds of Europe are being consumed with alarming rapidity. The desperate shortage of meats and fats is growing steadily worse. Our Allies are short of certain foods that we must supply if we expect them to carry on.

And as we supply them, as our imports are curtailed, as our fighting men consume more than they do in civil life, and as we fail to increase our production rapidly enough . . . we, too, become short of certain foods.

Former President Herbert Hoover, speaking before a conference of the Governors and Representatives of twelve Mid-Western farming states in Des Moines on March 15th, sounded the warning that American agriculture, beset by Washington bungling on manpower, farm machinery and price systems, strangling production and distribution, is facing a deterioration which may bring on a national food shortage such as led to the collapse of Russia, the defeat of Germany in the first World War and the fall of France in the present war. Unless this deterioration is stopped, warns Mr. Hoover, we cannot hope to win the present conflict.

Complications of similar magnitude face the food processor and the distributor.

Never in the history of the world has man's dependence on food been so crucial. Yet it is not easy for us to grasp the full significance of the crisis. We are so accustomed to finding milk, eggs and butter on our doorsteps every morning, we are so used to filling our pantries from the shelves of our grocers and markets that we accept food as something that is due us on demand. We do not stop to think that we never are more than a few meals ahead of famine.

But this picture has changed. Now we are faced with food rationing, and every day the shelves of our food markets become more bare.

* * *

Let it be noted that the appointment of two Food Administrators has not solved the food problem. It is still with us; daily it becomes more critical. Unless it is solved, and solved quickly, the very food that ex-Food Administrator Wickard said would "win the war and write the peace" may lose the war and lose the peace.

Put very simply and clearly, the food problem amounts to this: we are trying to feed upward of 200 million people. We are trying to do it with the farms and other facilities that heretofore have been capable of feeding about 145 million people (our present population plus a 5% surplus).

Had the Government foreseen the need and planned ahead, we could have begun by 1941 the enlargement of our farm production and food processing capacity. Two irreplaceable years have been lost!

The gravity of the situation becomes apparent when we consider that 50,000 factories are required to process our foods. Food processing not only is America's biggest industry—it is one of America's most important for, without processing, most foods would perish before they could reach the consumer. The term "processing" covers the salting, drying, smoking, pickling, chilling, canning, packing and other methods of preservation that make it possible for us to eat in 1943 food that was produced in 1942. Few realize that most of the food we shall eat in 1943 was produced and processed last year, that most of the seed we plant this spring will grow food for 1944 or perhaps later.

In one important process of preservation, tin and rubber are vital materials. When the Japs captured Malaya and the Netherlands East Indies more than half of the world's tin and nearly all of its rubber fell into their hands. This forced drastic changes upon our entire food economy. The importance of tinplated steel containers, tops for glass jars and rubber gaskets is fairly obvious... metal food containers alone consume, every year, more than 2,700,000 tons of steel.

The aggression of Japan has snared our whole food industry in a maze of intricate packing problems. It has enforced recognition of a new principle of food technology, i.e., that the *method* of food preservation is determined by the *type* of container available. The tin, steel and rubber stringency compels many food processors to adopt

unfamiliar methods – methods that call for a great deal of new equipment. This, in turn, involves the use of critical materials that are so urgently needed for other war purposes.

This conversion of the food processing industry to meet these exacting restrictions has been greatly complicated by two factors that have increased its wartime burden. Indeed, it is these that provide the principal reason for civilian food rationing.

The first of these is the task of feeding our armed forces overseas. Allied ships are being sunk at an alarming rate and the loss of cargo is considerable.

The second factor gravely augments the first. Under Lend-Lease our country is undertaking to feed our Allies to the extent of approximately 60 million people.

Types of food required for Lend-Lease and the armed forces are the finest we can produce. They are the high protein foods, especially meats, cheese and milk; and the protective foods which rate high in vitamin content. Peculiarly enough, the more valuable a food is from a nutritive angle, the more specialized is the processing required to preserve it.

The food processing industry, handicapped as it is, is meeting today's challenge with resourcefulness and enthusiasm . . . despite container complications and shipping shortages.

This is the tenth of a series of editorials appearing monthly in all McGraw-Hill publications, reaching more than one and one-half million readers, and in daily newspapers in New York, Chicago and Washington, D. C. They are dedicated to the purpose of telling the part that each industry is playing in the war effort and of informing the public on the magnificent war-production accomplishments of America's industries.

It is accomplishing its Herculean task by resurrecting and modernizing a method of food preservation that is as old as mankind. Probably you have read a great deal about dehydration. You actually may have eaten dehydrated food, but right now nearly every bit of dehydrated food is earmarked for the armed forces or for Lend-Lease.

Food processing never will be as spectacular as the production of bombers or tanks. But under today's conditions, the performance of the food processor is no less important . . . no less inspiring. When we consider that dehydrated food is compressed into solid blocks with a density nearly equal to that of coal, so that almost a whole meal can be carried in a vest pocket, and that half of the shipping space is thereby saved in transportation, we begin to appreciate what the processors have contributed to meet the food problem imposed by the war.

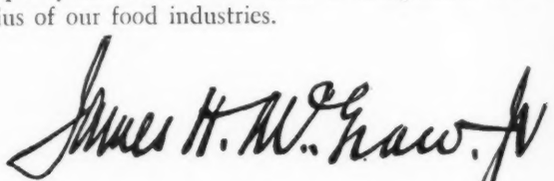
But they have not only contributed new methods, they are achieving new highs in production. And now they are asked to do what borders on the impossible. Consider dehydrated egg powder. Normal production in pre-war years was about 3,000,000 lbs. In 1940 this was increased two and one-half times, in 1942 it was stepped up again, this time forty-fold. And in 1943 the call is for another 60 per cent boost, to make a total of 480,000,000 lbs. Dried milk powder production of 350,000,000 lbs. in 1940 must be increased to 685,000,000 lbs. in 1943.

Vegetables, which were a small item to the processor before the war, now are dehydrated in enormous quantities. The vegetable dehydration industry has had to grow by leaps and bounds without benefit of the high priorities accorded to arms, ship and aircraft building. Production of dehydrated vegetables in 1942 was four times that of 1941, and 1943 calls for a sixteen-fold increase over 1942.

Total dehydrated food production in 1943 is scheduled at 1,750,000,000 lbs., dry basis . . . *all for export*. Multiply that by 10 and you have a rough approximation of the astronomical amount of raw materials that will have to be produced.

Many problems remain to be solved in the troublesome days that lie ahead. But with all his resourcefulness, man has little control over the weather. A severe drought could wipe out all of man's carefully laid plans. If we are tempted to reassure ourselves with the thought that the food situation probably is not so serious as it is painted, it will be well to remember that last year's crop increase over 1941 was due to better than average growing weather.

The war-bred food crisis that now confronts us will be met only by immediate measures to insure a food production ample to allow for adverse weather conditions. The food processing industry is capable, but has not been granted the needed help, in coping with its tasks. The food problem as a whole involves all three functions of production, processing and distribution. And if we are to master the problems that now beset us, all three of them must be coordinated under a single administrative control. "Food will win the war and write the peace". But if American food is to do that double job, we must develop a capacity for food *administration* comparable with the genius of our food industries.



President, McGraw-Hill Publishing Company, Inc.

PRODUCT ENGINEERING

GEORGE F. NORDENHOLT, *Editor*

Pitfalls in Post-War Designing

BECAUSE OF SUCCESS in converting to war production, many companies have been led to believe that they can make almost any product successfully. Furniture manufacturers who are now building wooden airplanes, stove manufacturers who are now making bombs, safe builders now producing guns, and textile machinery companies now making machine tools have discovered that there is nothing mysterious about their new fields of production. And even those manufacturers whose war production is closely akin to their regular peacetime products, seeing the success of the companies that converted to making war material of a character entirely foreign to their pre-war products, have been impressed with the fact that nearly all manufacturing is fundamentally the same. This will probably lure many companies into grave difficulties.

The beginning of any manufacturing company's success or failure lies in the design of the product. Unless the engineers of the manufacturer concerned are well posted on the products they are designing, they cannot be expected to be able to analyze service values and sales values and translate them into engineering drawings. This, however, is only one of the many reasons that make it almost impossible for a company to be successful in a field entirely foreign to that of its experience. To develop products in new fields, a company must have not only an exceptionally broad range of engineering talent in its organization but also plenty of cash.

Only a company in a strong cash position is able to spend the amount of money required to translate a patent into a salable product. A medium-sized company that branched into the design and manufacture of fractional-killowatt turbo-generators spent more than $200,000 before the first one was sold. Even when the invention relates directly to the product regularly manufactured, the development costs are extremely high.

Many manufacturers have proved to their own and to everybody else's satisfaction that American industry can readily convert from one line of products to the manufacture of perfected designs of an entirely different line. However, it does not follow that in commercial production a company can convert successfully to the manufacture of new lines if it is required to develop the design of those new lines within its own organization and at its own cost.

Other fields almost always look greener and the tremendous possibilities in one's own pastures tend to be overlooked. A manufacturer of washing machines might contemplate embarking on the production of electrical devices, failing entirely to visualize that there are nearly unlimited possibilities for new designs of post-war washing machines. If he investigates, he might discover many opportunities for the development of full-automatic home washing machines, the use of entirely new materials and the incorporation of sales and service features never thought of before.

The maker of sheet-steel lockers might be tempted to go into the manufacture of airplane parts, little realizing that he is in an enviable position to develop new lines of sheet-metal structures for applications other than the conventional lockers. Such applications might include sheet-metal built-in closets for the home and sheet-metal cabinets or housings for other purposes. There is also the boundless opportunity for such a manufacturer to scrutinize the possibility of using new materials, new types of constructions and new designs that possess outstanding sales features.

One can readily visualize innumerable examples in which the post-war opportunity for the manufacturer lies not in going far afield and pioneering in the unknown, for which he might be poorly equipped, but rather to put all of his efforts to bringing his pre-war products up to date as measured by the design possibilities of the post-war period.

WARTIME DESIGN NEWS

SIMPLIFICATION BOOMS:

Simplification and standardization of civilian and military products is in full swing, piloted by WPB and encouraged more or less from the sidelines by OPA, (PRODUCT ENGINEERING, Jan. 1943, p. 3.)

Within one month, early this year, WPB put out approximately a dozen orders cutting down on little-used lines and establishing specifications for allowable products. More are in process. One big boost came when Economic Stabilizer James F. Byrnes endorsed "simplified and standardized utility articles." Additional encouragement was found in the joint agreement by war agencies on the terminology "war model" for specified commodities which have been through the simplification mill. The move ostensibly was to eliminate confusion between bureaus, all of which were labelling results of essentially the same activity as "victory model," "utility model," "simplified model" and "war model."

Army and Navy cooperation has been obtained, an indication that there is no kidding in this program for, normally, the services are jealous indeed of their complete jurisdiction over design and construction of their own equipment. With WPB as umpire, the services are working toward standardization of specifications for radio and electronic components. In another instance, all air-cooled engines except those for aircraft and motorcycles were simplified and standardized and only a limited number of models approved for production. The order affects engines used by the services as well as those for civilian use. The services have also agreed in many cases to standardize components used in similar weapons.

Aims of such a program are obvious and far-reaching. Considerable savings of manpower and material are made possible, production is increased, inventories are reduced and the replacement part problem is simplified, particularly in the case of intra-service standardization.

WPB, for instance, estimated that its simplification and standardization in 1942 saved 600,000 tons of steel, 17,000 tons of copper, considerable quantities of other materials and man-hours enough to build 23 Liberty ships. Between February, 1942, when the first simplification order was issued, and the end of the year, 100 limitation orders affecting 315 products were issued. Other economies include 180,000,000 yards of cloth, 30,000 tons of leather, 450,000,000 board feet of lumber, 227,000 tons of pulp, 35,000 tons of solder and 8,000 tons of tungsten.

An idea of how specific lines have been reduced may be obtained from the following figures: Certain valves and fittings, reduced from 4,030 to 2,500; light bulbs, 3,500 to 1,700; heavy forged hand tools, 1,150 to 357; mechanical water coolers, 27 to 8; manual and special-purpose wood saws, 800 to 210; industrial power trucks, 221 to 50; x-ray equipment, 100 to 25; auto chains, 14 to 3; auto storage batteries, 100 to 16; textile and paper shipping bags, 100 to 12; chemical fertilizers, 800 to 90; steel wheels and tires, 500 to 50; Douglas fir plywood, 4,300 to 300; enamelware, 450 to 25 and fluorescent lighting fixtures, 200 to 2.

WPB recently issued National Emergency specifications for structural steel shapes, steel axles and forgings, mechanical steel tubing and rails and track accessories. These specifications, embodied in Schedules 4, 5, 6 and 7 of order L-211, define varieties, shapes, compositions, types, grades and qualities. Large reductions in dynamotor brush size and models was forecast by the Carbon Brush Industry Committee at a recent meeting with WPB.

Other recent WPB simplification orders:

Sixteen types of picks and all copper-headed tampers were stricken from the allowable list of heavy hand-forged tools under Appendix A to Schedule IV, order L-157. The move took 20 more types off the total of 360 allowable products. Earlier orders and amendments cut it from 1,150 to 360 items.

Types of sterilizers were restricted under Schedule A, order L-266, with sizes and materials under restriction.

Increased production of cotton textiles is the aim of amended order L-99, which affects 20 percent of all looms in the industry. The order, which lowers the filling count for cotton fabrics, will center production on durable and staple fabrics, with an estimated 230,000,000 yards additional production.

New patterns for wood furniture were banned and a cut of almost two-thirds made in existing patterns under order L-260. Manufacturers are limited to 35 percent of the patterns offered during September, 1941, or to 24 patterns, whichever is greater.

Builder's finishing hardware, which last December was cut to 3,500 items from 27,000, has been further reduced to 2,200 under Schedule I of order L-236.

An over-all reduction of 74 percent in the number of models and sizes of portable construction concrete mixers, truck mixer-agitators and contractor's dewatering pumps is imposed under Schedules V, VI and VII of order L-217. Repair parts are exempted.

Five simplification practices for electric-motor controllers are contained in order L-250. Design must be of the simplest practicable.

Effect of order L-272, which simplifies and standardizes control valves, liquid-level controllers, pyrometers and resistance thermometers is expected to be a 20 percent increase in production of the first two items and a 10 percent boost in the latter two.

WPB's radio division has instituted a line of "Victory" replacement parts, standardized to fit virtually all receiver models now in use. Electrolytic condenser types have been reduced from 350 to 9, tubes from 700 to 114. Parts, which will be available about April 15, will be manufactured in sufficient quantity, under present plans, to keep about 95 percent of all existing sets in use. The line includes paper-dielectric condensers, volume controls, power and audito transformers and chokes.

PACKAGING STANDARDS:

Precision-built equipment which reaches the fighting front in unusable condition because of improper packaging is worse than useless, for its cost is counted in dead men and lost campaigns. Because just too much of this has been happening, the Army, Navy and six civilian war agencies have agreed on packaging specifications aimed at getting the goods to the front in fighting condition.

The standards, contained in a 200-page booklet and bearing Army No. 100-14A and Navy No. 39P16a, were drawn up by WPB's Container Coordinating Committee, working jointly with the services, Department of Agriculture, Treasury Procurement, Lend-Lease, War Shipping Administration and the Office of Defense Transportation. They cover all war matériel except ammunition, subsistence items, clothing and a few special articles, such as aircraft, which already are under special specifications.

The standards are being written into all contracts for covered items for military or lend-lease shipment. Existing contracts on which shipments have not yet been made are being overhauled to get the new standards into effect as rapidly as possible.

Application of the new standards is to be accompanied by a two-phased campaign to teach proper packaging methods and to broaden the understanding of their necessity. For the first part, the Forest Products Laboratory has opened courses of instruction for ordnance inspectors and contractors. The second phase is a promotional campaign to get management to assign the same precision effort to packaging that it has to production.

In general, the specifications don't call for vastly different containers and methods than are now being used. Definitely, the new rules are tougher. They have to be. Shipments to Gen. Montgomery, for instances have had to cross the equator twice, and between crossings, skirt the Antarctic around the tip of Africa. But despite the rigidity of the standards, contractors are allowed much latitude.

WANT TO ENLIST?

Mechanical engineers, up to 50 years of age, who have a yen for Navy duty can get it—afloat or ashore—as operating, maintenance and inspection officers.

Operating officers with experience in diesel, steam or electrical engineering can get sea duty. Maintenance officers can get duty afloat or ashore on assembly, maintenance and repair of aircraft engines and electrical or mechanical machinery or equipment. Inspection officers can get shore duty on supervision and follow-up of production and production equipment, as well as duties pertaining to priorities, material procurement, plant security, liaison with industrial and governmental agencies and general administration work.

Candidates must meet the 50-year age limit, have a degree in Mechanical Engineering or 10 to 15 years of experience in mechanical engineering fields. Experience must be evidenced by having had responsible charge of work. Candidates also must meet Naval physical requirements. Application may be made to the Office of Naval Officer Procurement, 33 Pine Street, New York City. This appeal is being distributed through the American Society of Mechanical Engineers.

IDEAS FOR ENGINEERS:

Under the slogan "Ideas Win Wars—Once upon a time gunpowder was only an idea!" the Engineer School, Fort Belvoir, Virginia, has enlarged its suggestion system—nationwide and open to civilians and service personnel alike—for ideas on Army equipment.

Officers point out that in a year of operation among the troops, 11 percent of all suggestions have been approved and used. Suggestions need not go "through channels." Simply mail it, fully explained and accompanied by as many sketches as you care to send, to the Engineer School, at Fort Belvoir. Ideas are wanted on 31 subjects, including design, drafting, equipment, materials, methods, specifications and standards.

REDESIGN FOR FIGHTING:

From the Army's training camps comes the doughboy's ingenious answer to the widely-publicized Japanese knee mortar, (PRODUCT ENGINEERING, Feb., 1943, p. 65.) Disgusted with the attention given the Jap weapon, a highly mobile device which fits into the infantry weapons scale between the hand grenade and the regular mortar, U. S. mortar men figured out a "two-bit" home-made sight for our 60-mm. mortar. It is mobile as the Jap piece and still preserves its superior fire power.

The sight consists of a triangular piece of wood of almost any dimensions large enough to allow two readable scales. It is strapped on the bottom of the barrel. From a nail protruding from the corner nearest the muzzle hangs a pendulum which reg-

Official Photograph, U.S. Army

To give its latest anti-tank gun needed mobility, the Army mounted it upon a welded M-3 tank chassis as shown here. Faster than an ordinary tank, this destroyer has what U. S. ordnance officers believe is the best anti-tank gun in the world. The 3-in. rifle it mounts can knockout any armor known to be used on tanks today. The gun shoots either armor piercing or high explosive shell. Silhouette is lower than that of a tank. When not in action, the gun is carried facing rear. A 50-cal. all-purpose machine gun is mounted in the rear of the turret. Wherever possible in construction, whole sections are fabricated from armor plate, rather than cast, to save machine time. The turret is almost completely fabricated. In design, the M-10 was adapted as largely as possible for machine welding. Sloping armor plate tends to deflect shell hits.

isters on two scales drawn on the block. Upper scale represents distances from 100 to 400 yards and firing charge 0, the lower scale distances from 300 to 700 yards and firing charge 1.

The supporting bipod, which bears the regular mortar sight, is removed to lend mobility via "shank's mare," and the base plate removed to save weight, cutting the weapon down to 10 lb. The mortar is held between the legs of the seated gunner who estimates the distance to the target and decides on the charge to be used. Then he angles the weapon until the pendulum cuts the proper scale at the estimated distance, aligns the piece laterally and fires.

A gunner can carry 12 mortar shells and the tube without difficulty. Projectiles are considerably more potent than those for the Jap mortar and their range is several times the distance that the Jap knee mortar can fire.

ORDNANCE OUTING:

Army Ordnance Department's weapons demonstration for the National Association of Business Paper Editors at Aberdeen Proving Ground March 9 left the 100-odd correspondents who saw it with new conceptions of the twin military virtues of firepower and mobility.

Weapons ranging from .30-caliber rifles to a 240-mm. howitzer, some of which may not be publicized and many of them quite new, and motor vehicles of all types and sizes, all dedicated to the proposition of "getting there fustest with the mostest," were test-fired in a day-long demonstration.

This correspondent came away with a feeling of awe at the demonstration and at the vast, cooperative job done by the Ordnance Department and American industry in conceiving and creating these tools of war. While few civilians have the means of comparing U. S. armament with that of other nations to determine the best models, probably none of the visitors doubted the statement of high ordnance officers that our line of military hardware, complete from end to end, is the best in the world.

The demonstration started with rifles, which correspondents were allowed to fire, and progressed through mortars, small anti-tank guns, field pieces, anti-aircraft guns and howitzers. These weapons were mounted on tanks, half-tracks, tank chassis and gun carriers with more varieties of mounts than most people, including Hitler, ever knew existed.

At the automotive testing area, 15 types of vehicles were demonstrated and explained, including the renowned "Priest," (PRODUCT ENGINEERING, Jan. 1943, p. 3, March, 1943, p. 129), light and medium tanks of new and old vintage, seven different gun motor carriages and the German "Volkswagen." (PRODUCT ENGINEERING, March, 1943, p. 129.)

In the Foreign Material museum correspondents inspected hundreds of different automatic weapons and auxiliary equipment, after which they shot questions at Brig. Gen. G. M. Barnes, assistant to the Chief of Ordnance.

STEEL THAW:

Steel intended for use in now-halted production of civilian items is being put to war use at a rate in excess of 70,000 tons monthly. Volume is expected to peak in May, continue for some months and then decline as inventories are exhausted.

The transfer from shelves to machines is done under auspices of Steel Recovery Corp., a $400,000,000 RFC subsidiary formed last May to get the metal into the fight. WPB estimates that the program will affect more than 100,000 inventories. Similar programs are under way to recover other critical metals.

MATERIALS:

Alloy-Steel ingot production for aircraft and other use rose to a new monthly all-time high of 1,260,000 net tons in January. The figure is 300,000 tons above the average monthly output last year. An aircraft alloy-steel section has been set up in WPB's steel division to help speed deliveries to aircraft manufacturers.

Domestic Silver use by non-essential industry has been restricted to half the amount used in 1941 or 1942 under order M-199. Certain small producers are exempt from the order, which is expected to conserve 25,000,000 oz. in 1943.

Non-Ferrous Metals and Stainless Steels for use in manufacture of certain parts for oxy-acetylene apparatus are restricted under order L-268. In addition, the order provides that no order for oxy-acetylene apparatus shall be accepted or filled unless it bears a rating of AA-5 or better.

Marine Paint materials are getting so tight that their use, particularly by civilians, may have to be restricted. Maleic-treated oils will not be available for civilian use, and the industry has been asked to experiment with substitutes for castor, tung and oiticica oils.

Plywood made of soft wood has become so critical that WPB has been asked to study possibility of allocation of the available supply. The industry advisory committee reported that production is decreasing and that it will not meet total demands. Experiments on possibility of using Noble fir logs were recommended.

Copper and Copper-Base Alloys may no longer be used in manufacturing certain safety equipment items, under order L-114.

Lead Restrictions imposed by order M-38-C are no longer automatically non-applicable to orders rated A-1-j or better. Removal of the exemption for A-1-j orders was caused by increased assignment of ratings in the AA series, which leaves less lead for lower-rated orders.

Silica Gel has been removed from allocation control because of supply increases occasioned by new producers. Order M-219, which restricted uses of silica gel, has been revoked. All requirements may now be met fully and other new producers have still to enter the market.

Copper Scrap is the principal industrial salvage problem for 1943, according to WPB's industrial salvage division. Steel and iron scrap collections must be maintained at a high level, however. Copper scrap containing 0.01 percent or more beryllium may be delivered only to persons specifically authorized to receive such scrap, WPB ruled in supplementary order M-9-b, as amended.

Cork Restrictions under order M-8-a have been relaxed since the supply of cork in this country has doubled. Restrictions on processing and delivery of cork insulation board have been eliminated.

Shellac has been placed under allocation control by order M-106, as amended. Control of shellac is continued, but stocks of cut shellac in hands of retailers or ultimate consumers are exempt from authorization requirements.

Malleable and Gray Cast Iron may be used more widely in manufacture of pipe flanges, under order L-42, as amended. The move was taken to cut down the demand for steel for flanges.

Iron and Steel quotas for use in manufacture of low-pressure cast-iron boilers and repair parts were increased under order L-187. War housing and civilian replacement boilers are affected.

Signal Corps Activity In Designing New Devices

Scope of the vast network of interlocking activities of the U.S. Army Signal Corps in devising, developing, procuring, installing, and maintaining communications equipment for the various intelligence, command, and combat units. A glimpse of new developments and applications of electronic elements that will revolutionize post-war designs of timing and control apparatus used in all branches of industry.

"COMMUNICATIONS, particularly radio equipment, are the keystone of the whole military arch," said Maj. Gen. Dawson Olmstead, Chief Signal Officer of the Army, to a group of newly commissioned officers of the Signal Corps. "The maximum coordinated effort of the Infantry, Artillery, Mechanized, and Air Forces requires perfect timing and definite control. Signal communications are the means by which commanders exercise that control. . . . Never let any obstacles prevent the accomplishment of your mission to 'get the message through'."

"Getting the message through" in the Army Signal Corps means developing, procuring, and distributing the equipment, also training and assigning operators and technicians to transmit and receive essential information for the Army by radio, telephone, teletypewriter, submarine cable, motion and still pictures, V-mail and many forms of signalling the nature of which cannot be divulged. The vast network of interlocking activities connects the War Department Signal Center in Washington to the message centers of Army divisions all over the globe. The Signal Corps is also responsible for the effectiveness of the communications, meteorological, and ground photographic equipment, tactics and tech-

Operator receives data from meteorological station, then by means of deflection board makes corrections for range

niques used not only by Signal Corps troops but also by the personnel of observation posts, batteries, flight squadrons, and combat troops.

Most of the functions of the Signal Corps are directed by the two main divisions of the Office of the Chief Signal Officer, the Signal Supply Services and the Signal Operating Services. The Signal Supply Services comprise the Research and Development Division, Materiel Division, and the Field Service Division. The Signal Operating Services are the Army Pictorial Division, Army Communications Division and the Signal Troops Division. Additional duties are performed by the Executive Office, Office of Planning Director, Office of Fiscal Director, Office of Legal Director, the Control Division and the Communication Coordination Division. The task of the Communication Coordination Division is to keep the Signal Corps abreast of commercial developments, and to see that proper liaison is maintained with all services that use communications equipment.

In the field, the Signal Corps is responsible for the installation and operation of communications equipment down to and including the divisional echelon and laterally to adjacent units of the same echelon. Forward or assault units use equipment operated by their own personnel, but procured by the Signal Corps.

There is a signal company in every infantry division, and in every armored division, entrusted with maintaining communication from divisional headquarters down to the regimental command posts. Combat troops of the Signal Corps, organized into special companies and battalions, operate the signal centers of corps, armies, air bases, and major overseas headquarters; they serve with the ground forces and with the air forces; they put through our own messages, intercept the enemy's messages, and take bearings on enemy radio stations. The photographers among them are preserving on plastic film a dramatic and strategically informative photographic record of the experiences of the United States Army at war.

A field army is allotted a headquarters signal service company, a construction battalion, an operations battalion, a radio intelligence company, a depot company, a repair company, a pigeon company, and a photographic company. In addition to these Signal Corps units, a field army usually has additional Signal Troops of these categories in a General Headquarters reserve from which they may be drawn by an army which requires their services.

A tremendously important role is played by the Signal Corps as a supply

agency of the Army. In the Corps' procurement activities, it must provide for the development, specification, purchasing, inspection, issuance and maintenance of all communication, meteorological and ground photographic equipment used by the Army. This means not only the equipment used by Troops of the Signal Corps themselves, but also the radio sets and wire equipment used by troops of the infantry, field artillery, coast artillery, cavalry, the armored forces, and all of the complex radio equipment that serves so many purposes in the Air Forces.

Like all other branches of the Services of Supply, the Signal Corps makes every effort to simplify and streamline procedures so as to hold down to a minimum the number of steps required between the initiation of a development and the issuance of completed equipment to troops.

In the army organization, the laboratories in the Signal Corps Ground Signal Service and the Signal Corps Aircraft Signal Service operates under the Research and Development Division, which is a part of the Signal Supply Services. The latter operates under the Chief Signal Officer of the Army. The laboratories develop radio, wire, sound and light equipment used for communication purposes in the Ground Forces; meteorological equipment primarily for the use of Artillery and the Air Forces; and radio direction-finding equipment. Auxiliary equipment such as remote control devices, all types of power supplies, facsimile equipment, quartz crystals, microphones, and headsets are also the subject of research at the Signal Corps laboratories. Great progress has been made in the development of substitute materials to replace items which have been difficult to get. An important reduction in the requirements for essentials such as aluminum and rubber has already been made. The major portion of the work of the laboratories is the development of equipment which has immediate practical use in the armed forces.

The initial step in a development is a listing of military characteristics, in which are included a complete description of the qualities which the equipment must possess in order to satisfy a particular military purpose. Maximum allowable weight, size and shape, range desired, power source, and means of transportation are also specified, as well as desirable accessories and special features.

Although military characteristics are usually drawn up by the service test board of the particular fighting arm involved, army regulations provide that any one may initiate military characteristics. Often the basic idea originates with the operators or the communications sergeants.

When the equipment proposed is found by the War Department to be sufficiently desirable to warrant development, and if the proposal can be developed technically within a reasonable time, the Commanding General, Services of Supply, then directs the Chief Signal Officer to proceed with the development.

Experimental advancements, where factors such as speed of development and delivery of production quantities are important, are usually undertaken by industrial organizations under contract. Some developments are started by engineers in the Signal Corps laboratory and brought to a rough breadboard model stage, and the model then delivered to a commercial organization with a contract to produce finished service test models that may serve as manufacturing samples.

Preliminary tests are then conducted by Signal Corps Laboratory. After this the models undergo a thorough field test by the prospective military arm with the assistance and cooperation of engineers from the laboratory. The performance under test determines whether the models are approved, disapproved, or approved with exceptions.

After approval of test reports, the War Department establishes the basis upon which the equipment will be eventually distributed, and the Signal Corps Laboratory is directed to furnish complete procurement information in order that quantities may be ordered incorporating any necessary modifications.

Completely new developments are not always required. Often all that is suggested is a minor alteration in a component of existing equipment. A communication sergeant may recommend an improvement in a switch of a radio set based on his own experience in its operation. If his immediate superiors agree that his idea has merit, the recommendation is forwarded to the Signal Corps laboratories through the Chief Signal Officer. Here the idea is studied from the standpoint of field, technical, and production considerations. When for production reasons, it is not possible at once to incorporate an improvement the idea is filed for further consideration when a complete redesign of similar sets becomes desirable.

Typical of certain types of work, not developmental in nature, in which the Signal Corps laboratories are engaged, is the static suppression in automotive vehicles, tanks, and armored cars now used by the Ground Forces. This work has become increasingly important because of the vast increase not only in the number of vehicles employed but in the number of radio sets now used. All cars and trucks which are to be used in action or in transport close to the enemy lines are being equipped with devices that suppress the wild radio impulses broadcast from every spark plug in operation, and the static discharges from numerous rotating parts, which if not suppressed would cause interference with our own communications, as well as cause enemy radio equipment to groan and squeal, thus giving evidence that something in the vicinity was generating electricity. Then the enemy by turning in sensitive pick up devices can learn the location of the source of the interference and approximately what type of equipment is causing the disturbance. The exact method used to suppress the telltale electrical discharges is a military secret.

In addition, as the new types of radio sets are delivered to the troops in the field, the Signal Corps Laboratories also send out engineers and technicians to assist in proper installation of the sets, and to instruct the maintenance and repair crews.

Because of the great number of radio sets for army use which are crystal-controlled, the crystal industry has been greatly expanded and manufacturing methods have undergone many changes. Accordingly, the Signal Corps Laboratories have been engaged in the investigation and development of techniques adapted to production-line manufacture of crystals. Much research and testing of gasoline driven power plants to provide power for the newer types of radio equipment has also been necessary.

Many other projects and activities, all of which have a direct bearing on the supply of modern technical equipment to the fighting man in the field, are being pushed to the utmost. Since the chemicals in dry cell batteries soon become practically inactive at subzero temperatures, they present a very serious problem when used in equipment employed by the armed forces in Arctic outposts or in aircraft flying at high altitudes.

Fortunately the use of plastic materials for insulation is now possible because of its simultaneous development by the plastics and the electrical industry in recent years. Phenolics are now used as insulators in radio sets and power units. Washers and

disks punched from laminated plastics are used to separate and to insulate many electrical parts. These materials answer many of the requirements for electrical resistance, dielectric strength, lightness, ruggedness, and resistance to moisture and corrosion under the severe conditions to which military operations subject every item of Signal Corps equipment.

Officers and engineers in the Signal Corps Services are constantly looking for plastics the properties of which are not affected by extreme temperature changes—plastics that will not become brittle when subjected to low temperatures, and that cannot be deformed easily at high temperatures. Tests are conducted in temperature chambers having a wide range.

Having learned that some synthetic fibres absorb less moisture than does cotton or silk, the Wire Section is cooperating with manufacturers in a project to replace cotton braid on field wire with a synthetic fibre that will possess greater resistance to moisture.

In addition to using substitutes, ways for conserving material through changes in processing are being carefully studied. In certain applications, coatings 0.0004 to 0.0006 in. thick are now used instead of 0.001 in. hot dip galvanized coatings.

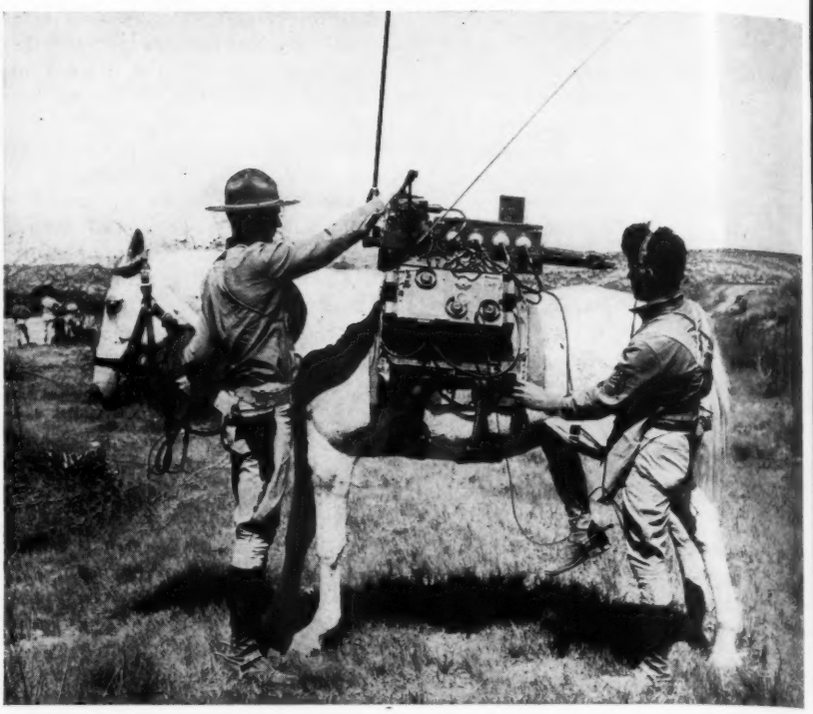
To save critical tin, the possibility of using solderless terminals on Signal Corps equipment is being studied. If this method of applying terminals proves to be satisfactory considerable time and labor will be saved in addition to the savings in solder.

The various uses of composition resistors and the characteristics required in each use, as well as the proportion of each use to total requirements, is another investigation that may lead to desirable standardization. Included in the reasons for this study are that binding materials may differ in various resistors, and because of variations in design and construction resistors of the same nominal rating are not always interchangeable.

Conservation Measures

The Army-Navy Electronics Production Agency also gives constant thought to drastic conservation measures wherever possible. An example of this activity is contained in the following illustration with respect to the mica situation.

It was found that a certain type of radio meter used in both air-borne and ground equipment especially called for the installation of mica capacitors. Monthly production schedules on one contract revealed that the meters required the installation of a total of 12,400 mica capacitors per month.



Transmitting and receiving set with hand cranked generator mounted on horse's back makes a highly mobile unit in rough country

Close application and study of this problem by the Production Analysis Group, together with the assistance and cooperation of the manufacturers, revealed that paper and ceramic capacitors could be substituted in place of mica without altering the cost and efficiency of the operating qualities of the set.

The result of this analysis was that over a hundred thousand critical mica capacitors were conserved on this one contract alone, thus helping to add a measure of relief to the then present serious mica capacitor situation. Also, making it possible to open up the way for the delivery of other important sets held up because of the dearth of this critical item.

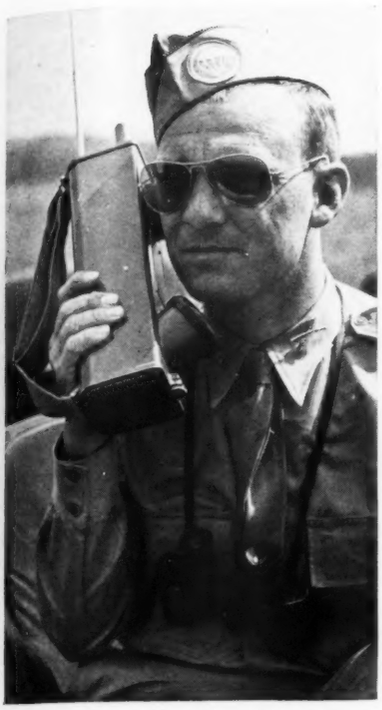
Aircraft Radio Laboratory

The Signal Corps Aircraft Signal Service has been organized by the Signal Corps to supervise all research and development, procurement, inspection, storage, and issue of aircraft radio and ground radio used for navigational purposes, in order that close coordination of engineering and procurement work may be maintained.

The Aircraft Radio Laboratory is in charge of all research, development, engineering, and inspection incident to design, procurement, and installation of radio equipment in aircraft and of ground equipment for radio navigation. Projects are set up and funds are allotted by the Chief Signal Officer. Research on these projects may be done by the Laboratory. But usually research is carried on in cooperation with the National Defense Research Council or is let on contract to the laboratories of commercial radio and electric concerns. Weight, power requirements, and form factor must be considered to facilitate installation in Army Air Forces airplanes.

To assure that radio equipment will perform satisfactorily in all parts of the world, tests are made under high altitude, extreme temperature, and high humidity. They are also tested for electrical and mechanical performance. After the equipment has passed all tests, the Laboratory prepares specifications for quantity procurement. Upon receipt of the new equipment, the Laboratory makes a mock-up on various types of airplanes. In the mock-up the equipment is installed and flight tested. For the guidance of airplane manufacturers, modification centers and depots, they are supplied with blueprints of mounting frames, brackets, and wiring diagrams.

Engineers of the Signal Corps are constantly revising, improving and redesigning equipment in accordance with information contained in field reports and new developments in industry. An excellent example of how



Officer using a Handie-Talkie to talk to pilot in a plane

equipment is being redesigned, to keep abreast of the demands of modern warfare, is the "radio jeep" or "handie-talkie". This "transceiver" equipment is a streamlined "walkie-talkie," such as has been used in operations in the Far East. The "walkie-talkies" weigh about 30 lb. The new transceivers weigh less than 10 lb., and can be carried easily. Despite their light weight features they are sturdy and almost foolproof.

The transceiver can be used both for receiving and transmitting over short distances. The equipment has a collapsible antenna which when not in use telescopes into the housing of the set. The instrument is turned on by pulling out the antenna. Sliding the antenna back into the box, turns the set off, and power is thus conserved. Effective use of the device requires some previous understanding of when messages are to be broadcast. Weather conditions have little effect on receiving and transmitting.

In the design of equipment used for Signal Corps communications are incorporated some of the most complex and intricate scientific principles with the help of American ingenuity. Many of the devices in use today might have been fantastic dreams in World War I. Mechanized caravans moving along the roads talk to planes and planes answer back, they both talk to a distant headquarters by recently developed portable, two-way radios.

Portable radio sets, called "snoopers," pick up enemy messages lurking in the air and furnish data from which operators can compute the direction from which the message came. That is why telephone and telegraph communications are preferred in the field if they can be used; the enemy may spot your radio messages just as you are equipped to search out his.

Mobile weather stations make meteorological observations for pilots and artillerymen. Even the wind drift is vital information to the crew of a field gun—its aim may be thrown far off if the gunners lack data on the velocity and direction of the wind.

A new device, for use by men drifting at sea on a life raft, consists of a balloon that carries an antenna from a rubber raft upon which is a hand crank set for sending out SOS signals. Planes flying many miles away can pick up the signals and determine where the drifting men are.

Criterions of design set up by the Signal Corps demand the seemingly impossible. But through ingenuity, research and experimentation the almost impossible has been achieved. Signal Corps equipment is compact yet accessible for maintenance repairs and adjustments, light in weight yet durable, withstands the heat and humidity of the Tropics as well as the ice and frost of the Arctics, operates on the ground and in the stratosphere, performs when stationary and when flying at fantastic speeds that subject the complex mechanisms to extreme gravitational effects. The effect of these developments on post-war design will be far reaching. In every field of engineering these new principles of control will be applied in the design of instruments and apparatus to speed up production, and to increase accuracy in calibrating and measuring operations.

Truly the Signal Corps communications are the very nerve centers of every branch of the Army from the doughboy in the trenches to the tail gunner in a Flying Fortress.

Field sets like these and many new types of telephone equipment have been developed since 1919

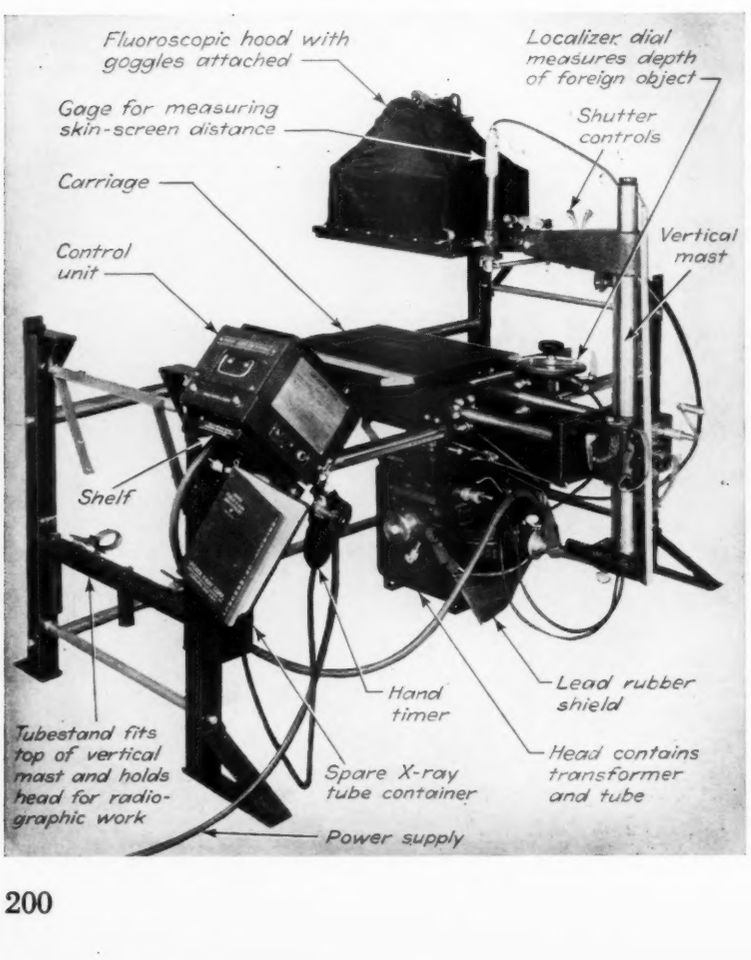
WARTIME DESIGNS . . .

X-RAY TABLE DESIGNED FOR PORTABILITY

The lightest weight, most compact X-ray field unit ever built is the claim of Picker X-ray Corporation for its new Army unit. This 400-lb. portable unit was conceived in 1940 and, without official encouragement, experimental models were made early in 1941. Later an unexpected request for delivery of four units within ten days was met by concentrating the company's entire facilities. The present unit is meeting air transportation requirements as well as satisfying the Army's X-ray needs.

The unit is intended primarily to locate shell fragments or other objects in wounds and is designed for continuous operation as a fluoroscope. However, it is also capable of taking X-ray pictures. The X-ray tube unit is designed to operate at a maximum of 15 milliamperes at 80 peak kilovolts.

The method of localization involves a known triangle with a fixed height measured between the focal spot and the screen, and a fixed horizontal base measured between two parallel lines on the screen. The depth of an object below the screen is always in direct proportion to the distance the carriage moves horizontally to make the shadow of the object move from one to the other of the parallel lines. The localizer dial, being geared to the table rail, indicates this depth. In actual practice the dial reading is corrected to indicate the distance of the object below the skin, the correction being the gaged distance from screen to skin.



Portable X-ray table is assembled at the place where it is to be used. All accessories, such as tube stand, focal distance checking gage, fluoroscopic hood, radiographic cone, and spare X-ray tube, are attached to the table when not in use so that the radiologist will not be handicapped if packing chests are removed or destroyed. Design was planned with all controls on one side of the table and arranged for convenience of the radiologist.

The fluoroscopic hood with attached goggles is a novel feature which permits fluoroscopy in daylight and eliminates the usual dark room tent. Hand controls instead of foot controls avoid trouble if the table is set up on muddy ground. Illumination is provided on the gage for measuring skin-screen distance and on the localizer dial at levels below that which would hamper eye accommodation. This illumination is cut off automatically during exposures. Fluoroscopic exposures are held by means of a pushbutton on top of the vertical mast and radiographic exposures are timed by a hand timer.

Horizontal or vertical radiography can be performed by placing the tubestand over the top of the vertical mast as a support for the head in various positions over the table.

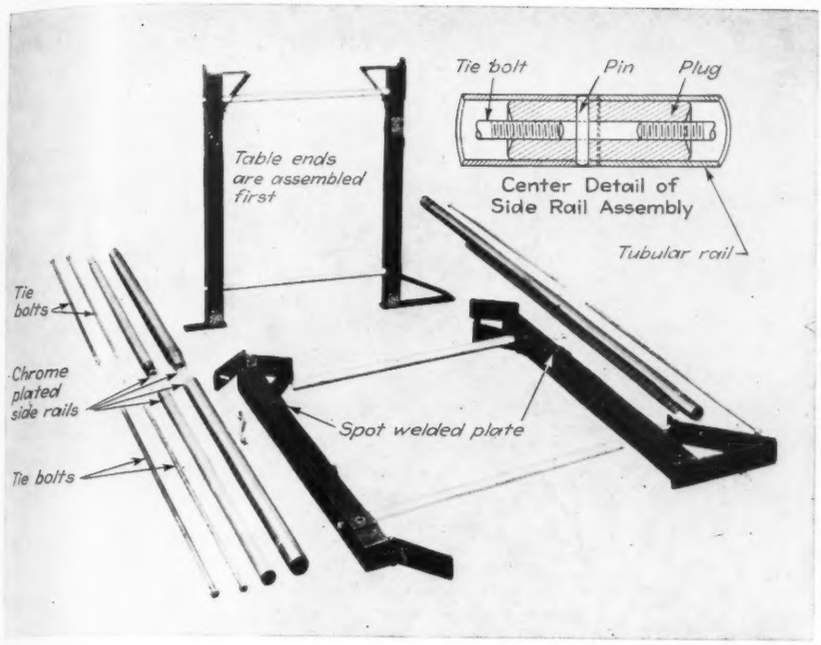
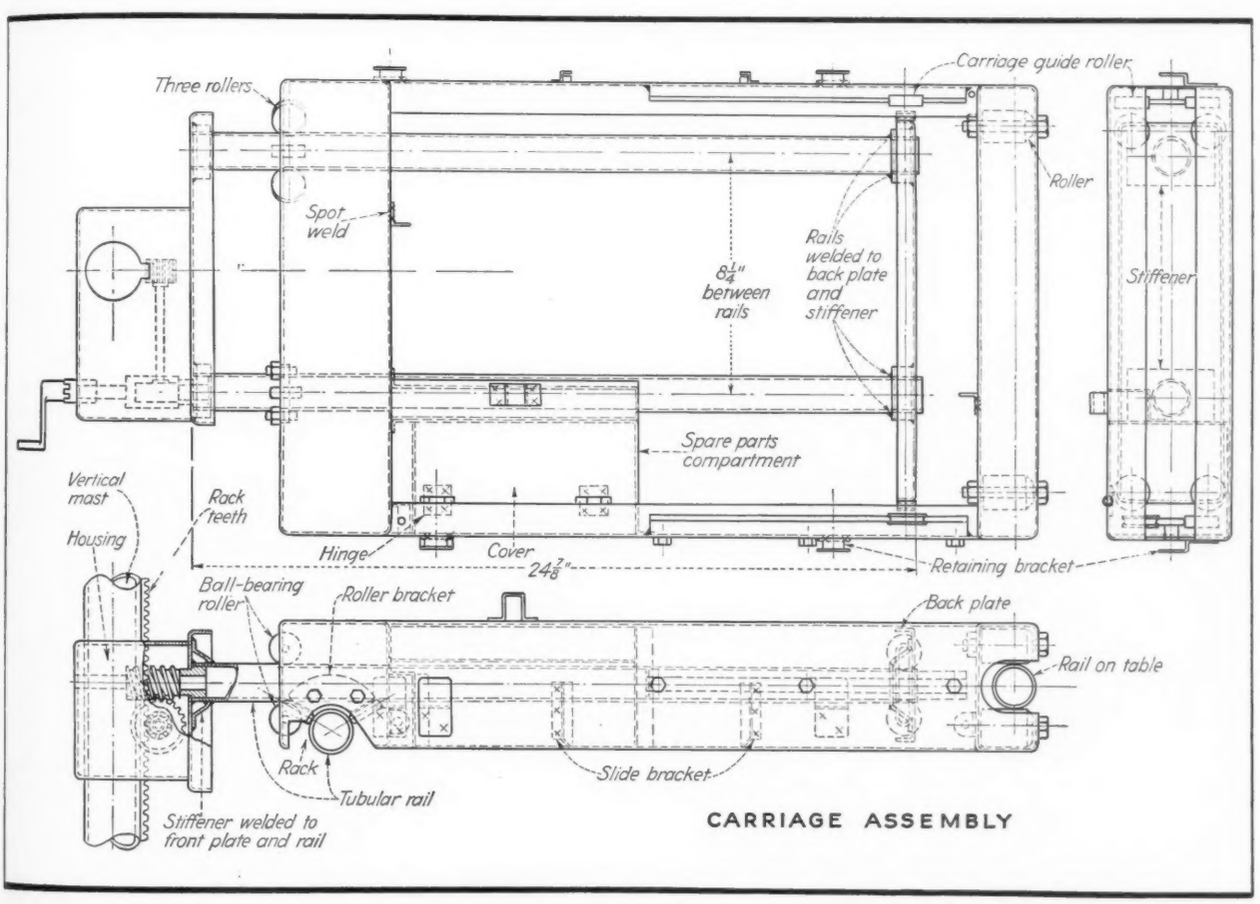


Table frame occupies only the space taken by the four corner posts when dismantled and packed because the tubular members and tie rods are all telescoped within these 2-in. square tubes. The round tubes are plated steel while the square posts, and all other fabricated steel members of the X-ray unit, are given a leather-like two-tone baked enamel finish.

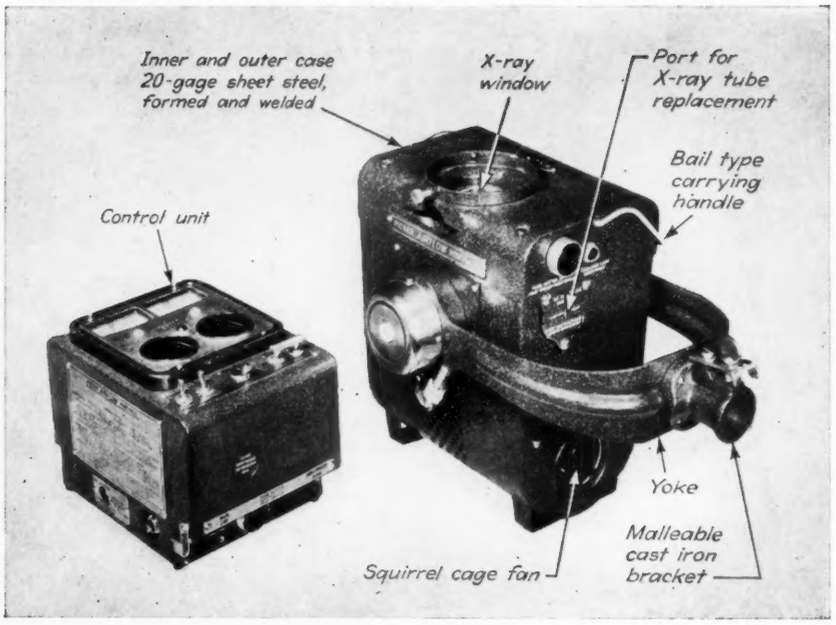
Hinged straps fold flat against the posts for packing. These straps are welded to the corner posts and held in place when the table is assembled, by the tiebolts that hold the tubular end rails in place. Lower straps give a solid footing on muddy ground and upper straps support a stretcher.

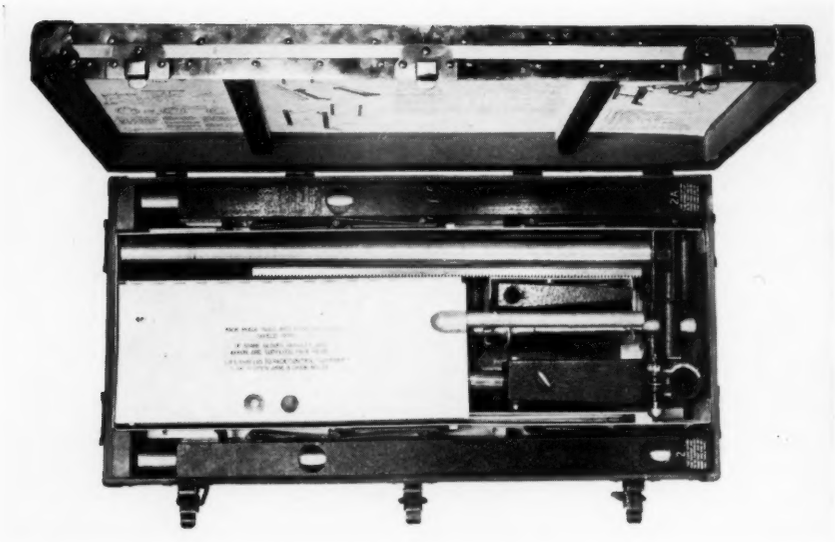
Rigidity is attained by passing rails through a clearance hole on the near side of corner posts and tightening their machined ends to the opposite inner wall of the leg by means of the tiebolts.

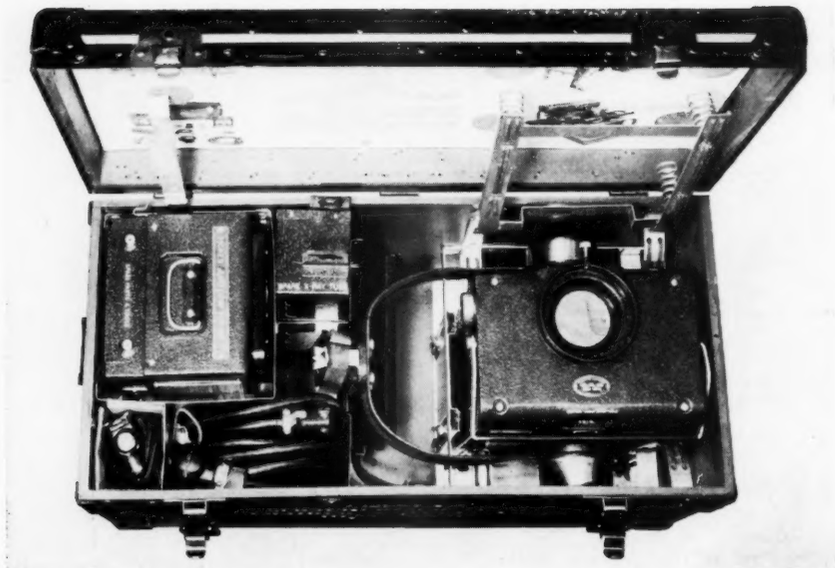


Horizontal carriage is of welded sheet steel construction. Sealed precision ground ball bearings give it finger-touch movement lengthwise and crosswise. Bearings on control side fix its position on table rail while those on opposite side allow for variations in distance between rails. For a similar reason one of transverse rails carrying the vertical mast is guided by three bearings while the other is guided by two. Spare parts and tools are kept with the unit in the compartment shown. Several brackets, which are spot welded to the carriage, serve various purposes.

Raising and lowering mechanism for mast is inclosed in box welded to carriage. Rack on mast, which passes through box, acts as a key to prevent rotary motion. Localizer dial and housing, not shown, are also mounted on the carriage. A gear on lower end of dial shaft engages rack on table rail. Play is removed by spring pressure. Dial expands measuring scale for increased accuracy and speed.







Transformers and X-ray tube are sealed in an oil-filled housing provided with expansion bellows to handle temperature changes. High voltage connecting cable is thus made unnecessary. Continuous fluoroscopic operation, an unusual feature, is made possible by a cooling system consisting of an internal motor operated oil circulator and a quadruple air blower between the housing and an outer shell.

Overheating and possible tube failure is prevented automatically by a thermal overload switch in one of the expansion bellows. This gives first a visual signal and then, if ignored, automatically cuts off the exposure until the temperature is again within safe limits.

A port at one end of the case permits tube replacements in the field. External means for partially collapsing the bellows prevent loss of oil.

The drawn steel hanger enables rotation about both horizontal axes, and any desired angulation may be held by quick-acting locks.

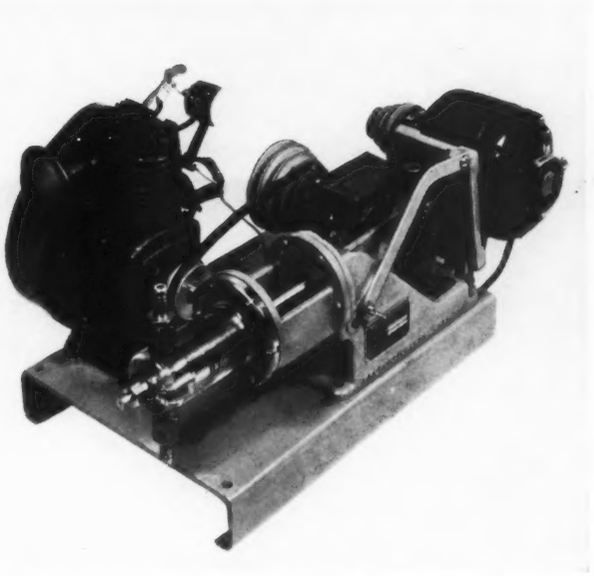
The control box is small and weighs only 23 lb., yet it has advantages not found in larger units. It adjusts itself automatically to 110 or 220 volts a.c. Its autotransformer has 20 steps of tube kilovoltage selection and a magnetic contactor prevents its exposure switch from carrying main primary current. An overload circuit breaker protects against excessive tube current. An ingenious means of expanding the meter scale length makes more accurate kilovoltage settings possible. The meters are mounted in sponge rubber to avoid vibrational damage. Meter windows are shatterproof glass and are protected further by a transparent plastic cover.

Two of three similar chests contain the entire dismantled X-ray unit. They are constructed of waterproof plywood faced on both sides with fibre and reinforced at the corners and edges with steel. Steel fittings riveted in place and heavy cord lacing hold individual parts and protect them from abrasion.

Visible in the upper chest are the telescoped table legs and frame. Below, the X-ray tube and transformer unit, the control unit and related accessories are packed ready for closing the lid. Instructions for packing and removing apparatus, as well as for setting up the X-ray table and equipment are pasted inside the lid.

EMERGENCY EQUIPMENT FOR WATER WORKS, UTILITIES

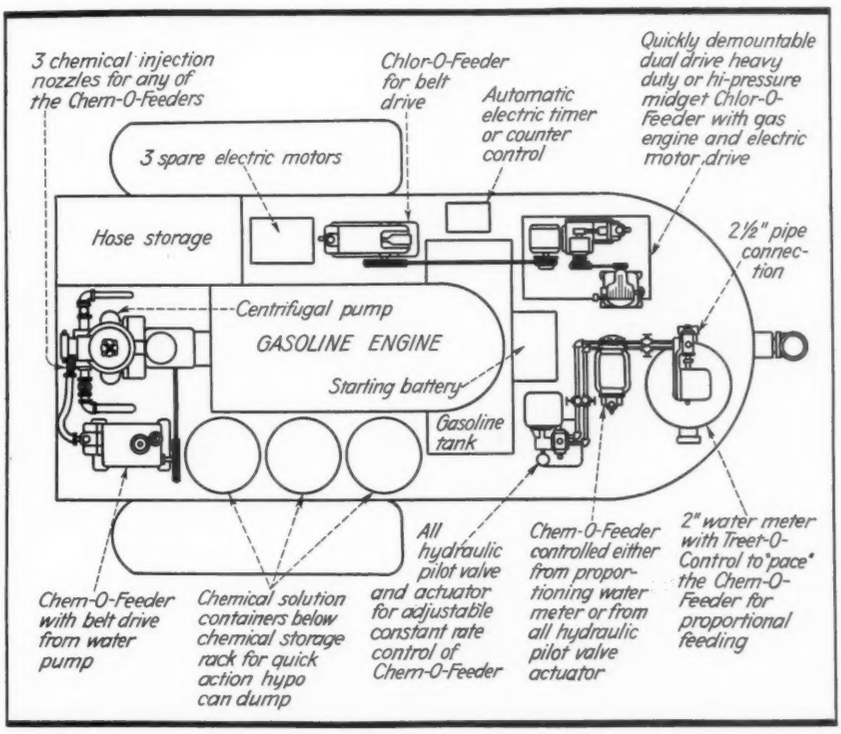
Mobile Blitz Buggy carries emergency equipment for fire-fighting, for gas infested areas and for purifying drinking water. In designing the buggy, the aim of the engineers of Proportioneers, Inc., was to provide a pump of ample capacity for combating incendiary attacks and war conflagrations, and that could also be used as a standby auxiliary water supply service to temporarily replace water plants, standpipes and storage tanks should they be put out of service by raids or acts of sabotage. Other objectives were to provide emergency equipment for sterilizing standpipes, storage tanks, and broken water mains or cross-connections, and also for washing streets and buildings with a chlorinated stream to counteract the effects of gas residuum.



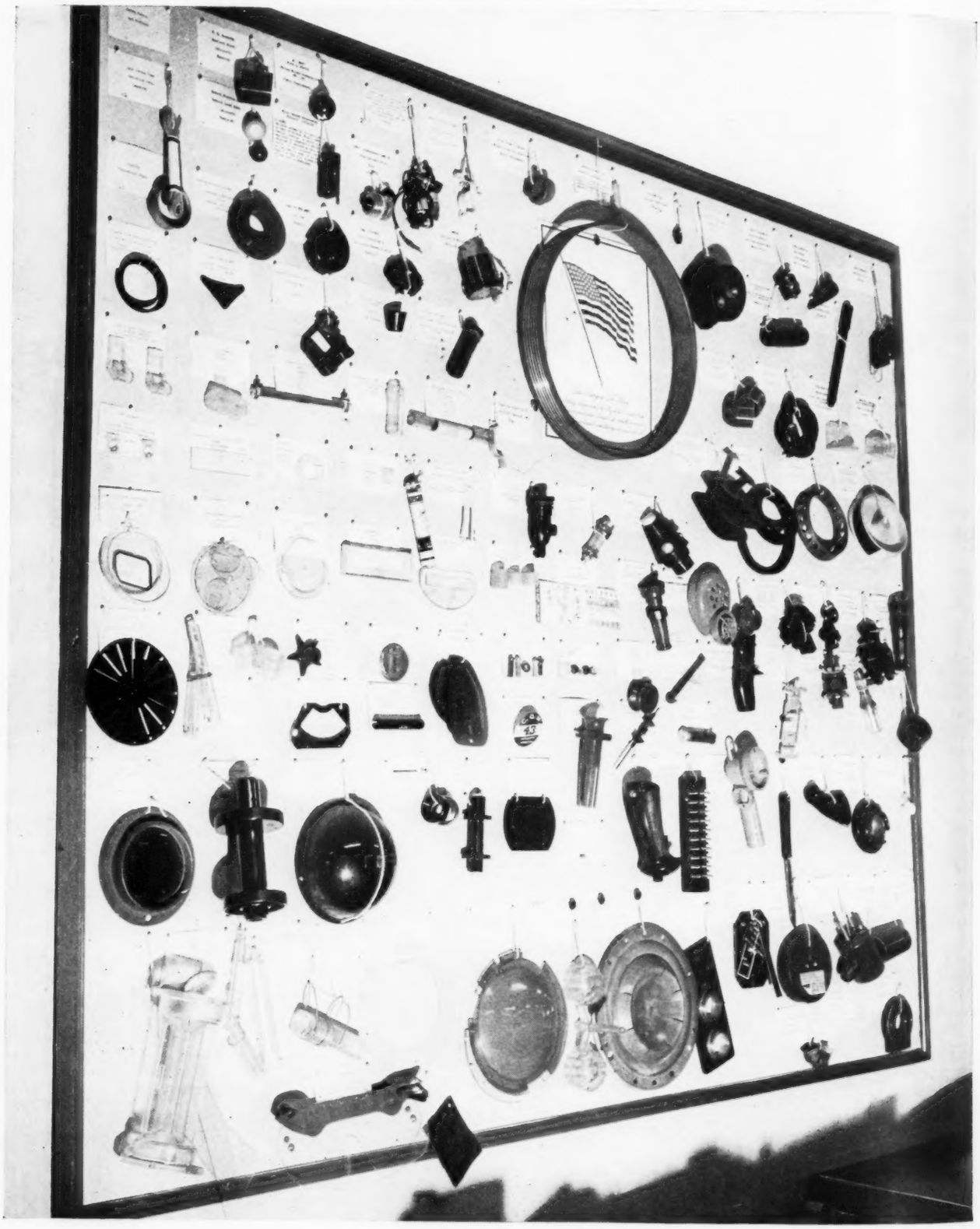
Chlorine feeder is a compact high-pressure unit mounted on a formed steel bedplate. The unit consists of a reciprocating single acting plunger pump, a gasoline engine and an electric motor. Gasoline engine is a ½ hp., 4 cycle, L-head, air cooled vertical single cylinder type, with a high tension magneto. Engine also has a pedal type crank for quick starting. Pump is connected to a worm gear speed reduction unit driven by a V-belt from either the motor or engine. Electric motor is mounted on a cast iron plate hinged at its bottom edge to the crank end of the pump frame casting. Top edge of plate is connected to pump frame with an adjustable stiff leg for regulating belt tension when motor drives pump. The pump cylinder is made of transparent methyl methacrylate plastic.

Centrifugal pump driven by an 85 hp. Ford V8 engine is the largest unit mounted on the mobile Blitz Buggy, arrangement plan of which is shown here. Pump delivers 200 g.p.m. at 200 lb. per sq. in., and discharge is 2½ in. Ball bearings in the pump are permanently grease packed. Engine is covered with sheet metal housing, the rear panel of which serves as an instrument board for the oil gage, ammeter, starting button, throttle control, choke control and ignition switch. Engine is equipped with an auxiliary cooler or heat exchanger connected so that the circulation water is turned back into the pump suction. Driven by belt from the engine drive shaft, an all purpose chemical feeder unit can be connected to the discharge side of the pump.

Steel floor of the truck is welded to chassis. Storage rack for hypo cans and box for residual test kit are made of sheet steel. On some models the box is coated with plastic paint to protect the steel from corrosion.


3 chemical injection nozzles for any of the Chem-O-Feeders
Chlor-O-Feeder for belt drive
Automatic electric timer or counter control
Quickly demountable dual drive heavy duty or hi-pressure midget Chlor-O-Feeder with gas engine and electric motor drive
3 spare electric motors
Hose storage
2½" pipe connection
Centrifugal pump
GASOLINE ENGINE
Starting battery
Gasoline tank
Chem-O-Feeder with belt drive from water pump
Chemical solution containers below chemical storage rack for quick action hypo can dump
All hydraulic pilot valve and actuator for adjustable constant rate control of Chem-O-Feeder
Chem-O-Feeder controlled either from proportioning water meter or from all hydraulic pilot valve actuator
2" water meter with Treet-O-Control to "pace" the Chem-O-Feeder for proportional feeding

116 APPLICATIONS FOR PLASTIC MATERIALS

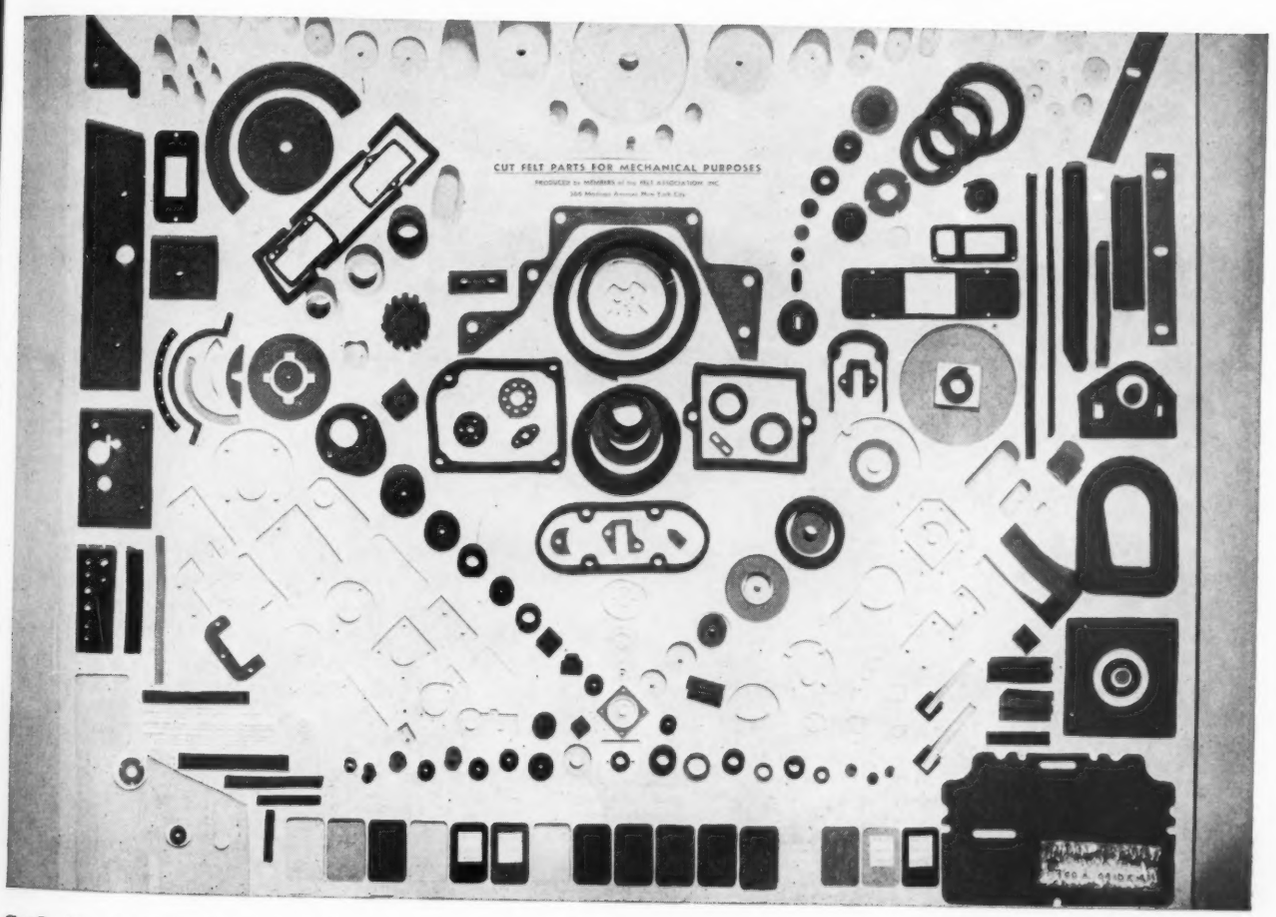


Twenty different types of plastic materials are used to make the parts displayed on this board, erected by WPB's Conservation Division. Most of the parts are original designs. In the others plastics have been substituted for various scarce metals, principally aluminum. The parts include sewing machine windows, construction light lens, auto lamp jewel lens, dial light lens, black out reflector and lens, eye shields, respirator cover, gas mask parts, switchboard plugs, plug fuse, wads for cartridges, shell fuze, hose coupling, hose nozzle, ball bearing cage, shoe string tips, cable bushing, poultry leg bands, gun switch handle, machine gun sprocket, submarine CO_2 indicator, Army water bag faucet, spark plug insulator, and index tabs.

CONNECTORS REDESIGNED TO SAVE ALUMINUM

Redesign of component parts of shielded electrical connectors for aircraft saves material, man hours and machine hours. Through redesigning it was possible to die-cast the rings in low-grade aluminum or zinc base alloy. Rings were formerly machined from high-grade aluminum bar stock. In practically all of the parts low-grade aluminum was substituted for high-grade metal.

RUBBER PARTS REPLACED BY FELT

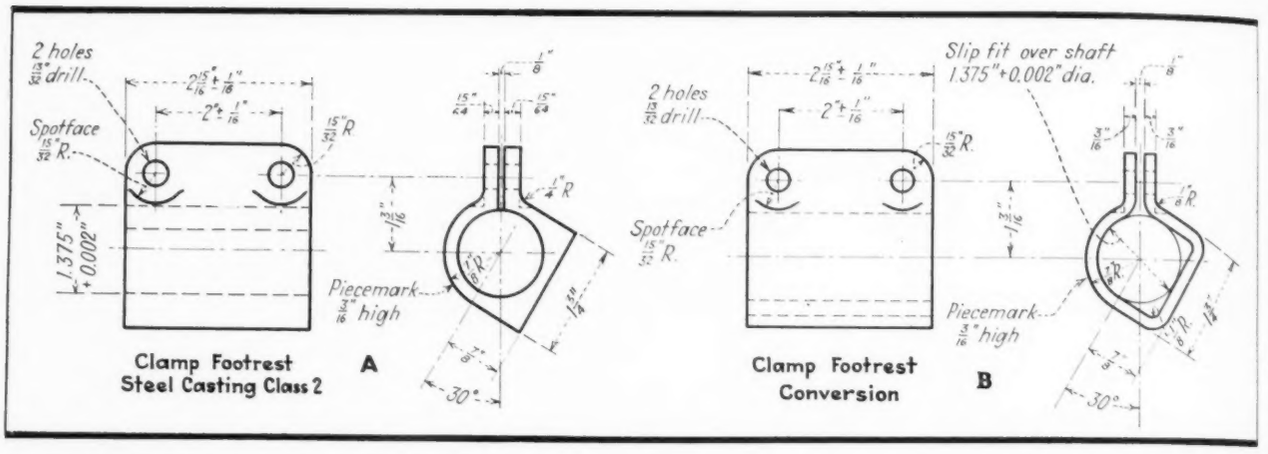


Gaskets, grommets and washers made of wool felt of various consistencies specifically designed to replace rubber are displayed by WPB's Conservation Division. Felt parts are treated with impregnating compounds to obtain stiffness, durability, waterproofing and other desirable qualities. Approximately 500,000 lb. of rubber have been saved by these substitutions.

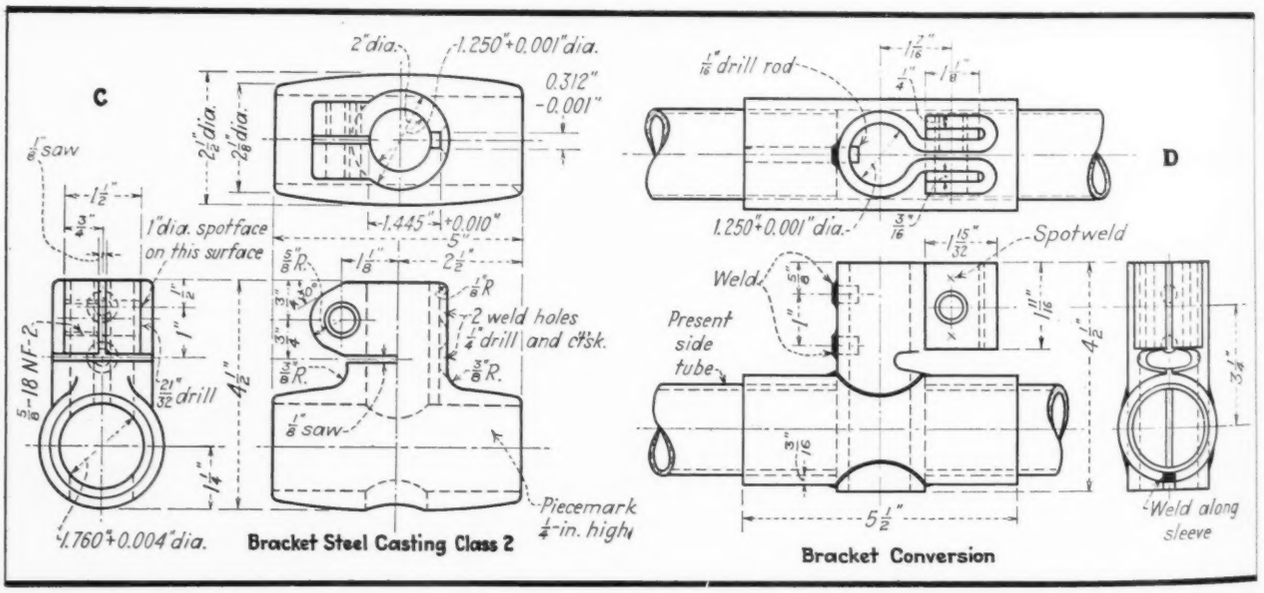
The felt materials are made from wool or a mixture of wool and other natural fibres by the mechanical operations of hardening and fulling, without spinning, knitting, or weaving. The parts are fabricated to blueprint dimensions by die cutting, punching, shearing, skiving, turning, sanding and other operations. Tolerances are in thousandths of an inch.

CAST ORDNANCE PARTS REDESIGNED FOR FABRICATION AS WELDED STAMPINGS

Present production requirements are using to capacity the machining, forging and casting equipment of industry whereas many stamping and drawing presses are standing idle. Nor is there any marked dearth of electric welding and gas welding equipment. In order to make possible a 50 to 100 percent increase in production without requiring a corresponding increase in manufacturing capacity, many parts being redesigned so that they can be made as stampings or welded assemblies of stampings. Here are a few conversions from castings to welded stampings developed by engineers of the Truscon Steel Company in cooperation with specialists in the Ordnance Department.

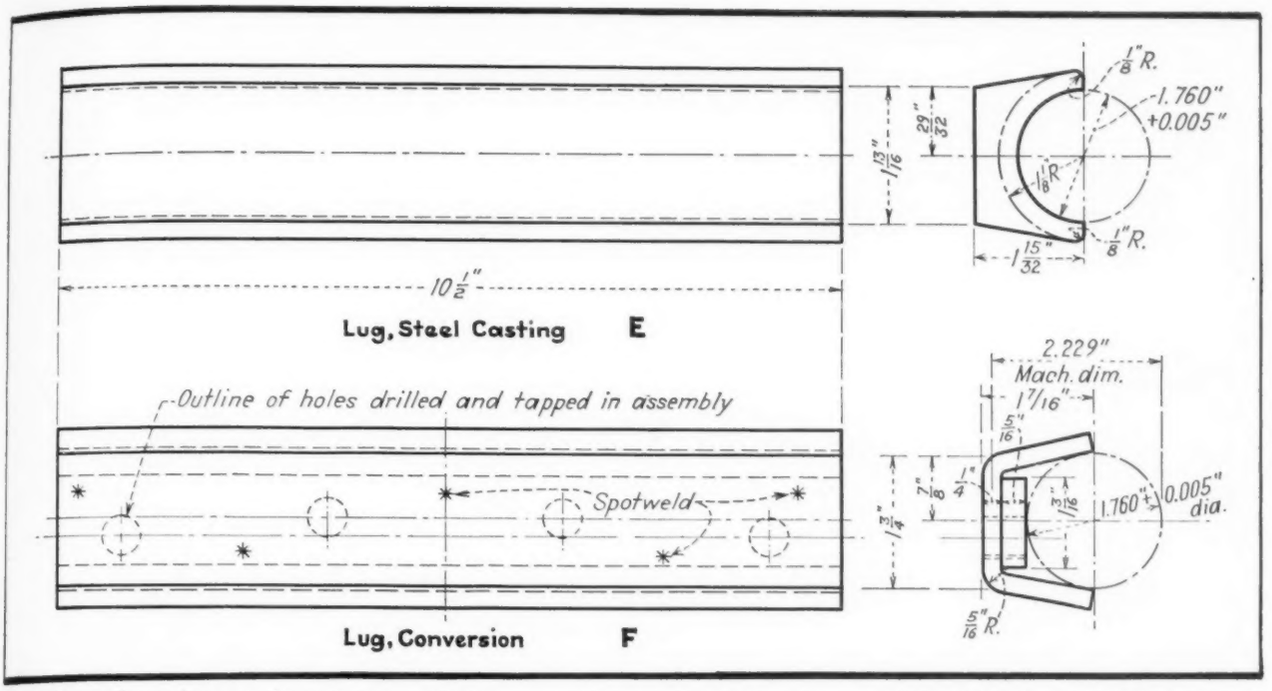


Clamp for footrest was a steel casting as shown at *A*, weighed 2 lb. Machining operations were: mill flat face, drill and ream $1\frac{3}{8}$ in. hole, drill two holes $\frac{13}{32}$ in. dia., spot face four holes, saw a split and face ends. Part was redesigned as shown at *B* to be formed from a low-carbon steel plate. Stamping weighed $1\frac{1}{2}$ lb. Only machine work required is drilling two $\frac{13}{32}$ in. dia. holes, and spot facing both ends of holes.



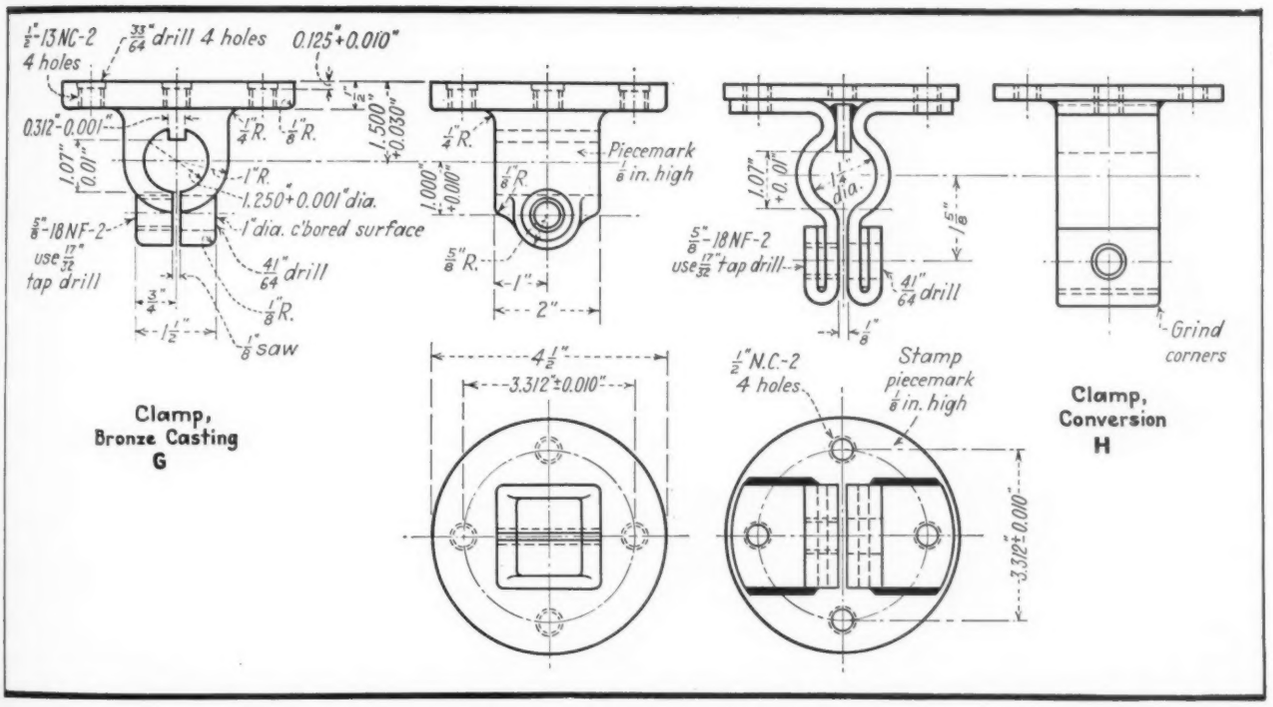
Bracket for connecting tubular members of frame, shown at *C* was a steel casting, weight 5 lb. Note amount of machining required—five holes drilled, three holes reamed, one hole counterbored, three holes tapped, two holes countersunk, two sawcuts, and keyway to be slotted.

To save foundry and machine work, the bracket was redesigned as shown at *D* to be made from flat stampings, formed to shape and then welded. Only machine work required is drilling and tapping for clamping bolt, and two drilled holes for drill rod that replaces square key. Material required for welded bracket was 4 lb. of low-carbon steel plate.



Lugs formerly made as steel castings, shown at *E*, weighed 5½ lb. each, and sometimes required straightening before machining the concave half round surface. In addition, the machining operations on the part presented obvious difficulties.

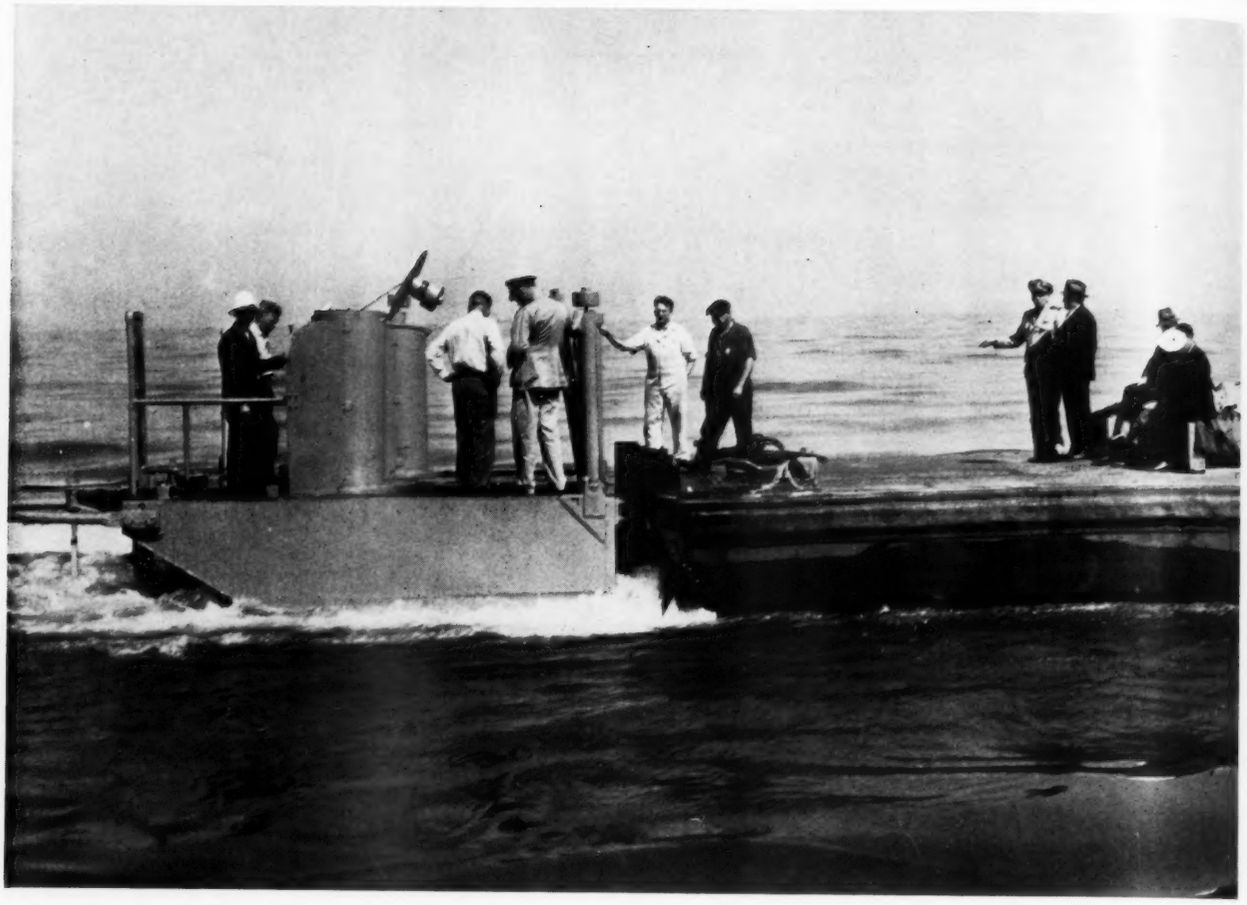
Lug was redesigned as shown at *F* to be made in two pieces out of strips, and held together by spot welds. Material required was 4 lb. low carbon steel. A saving of 1½ lb. per lug. Machining work was also reduced and simplified by eliminating half round milling.



Clamp originally designed to be made in small lots and to be cast in bronze, as shown at *G*, required excessive machine work. Flat 4½ in. dia. face was milled, 1¼ in. hole with tongue was broached, and casting was sawed through at the clamping boss, four holes were drilled and tapped, and another hole drilled and counterbored at one end and tapped at the other end. Casting weighed 4½ lb. in the rough.

Critical metals needed for alloying bronze to make part as originally designed were saved by redesigning the clamp for fabrication from stamped and formed steel pieces to be assembled by welding. Redesigned clamp is shown at *H*. With this construction, the only machining work required was that of drilling and tapping five holes, counterboring one hole. Tongue which was formed in original design by broaching operation is made in the redesigned part by welding a short piece of finished bar stock in between the horn-shaped pieces.

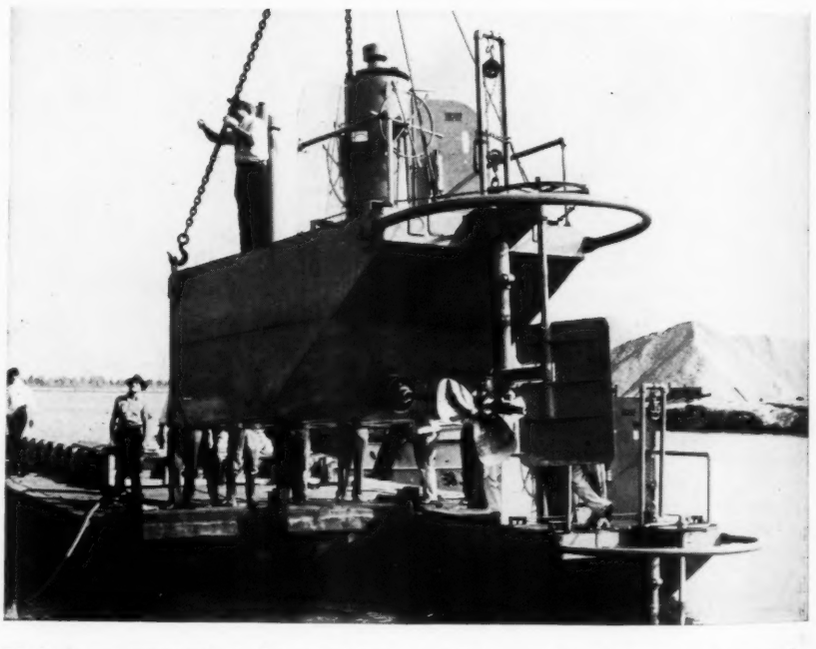
MARINE TRACTOR UNIT FILLS TUG SHORTAGE



Marine tractor unit that can be attached quickly to barges, scows and other types of flat-bottomed cargo carriers has been developed by Chrysler Corporation to help solve some of the water transportation problems incident to the war effort. Putting into use on inland waters cargo-carriers that are now idle, because tugboats are lacking, will relieve railroad transportation. Barges propelled by the marine tractor can also be used for carrying troops, munitions and supplies and landing them on any shelving beach, thus eliminating the necessity for cranes or other handling equipment.

During a test one tractor propelled a heavy steel barge at a speed of approximately 6 mi. per hr. With two units attached to the same barge, the speed attained was approximately 8 mi. per hour.

In addition to the marine tractor, Chrysler Corporation is building steel pontoons, 5 ft. sq. by 7 ft. deep. These are equipped with clamps for attaching one pontoon to another so that a vessel of any desired size can be assembled for carrying deck loads.

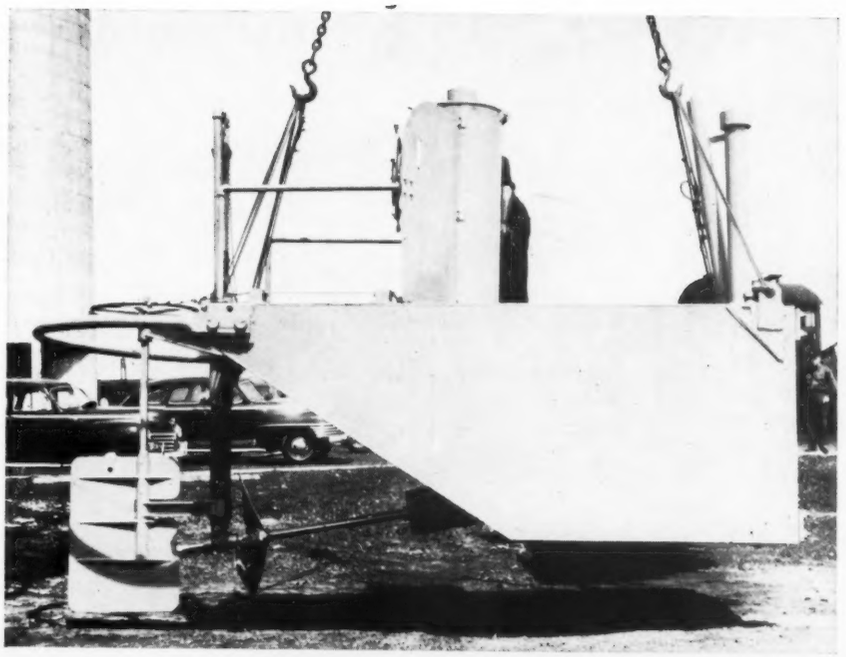


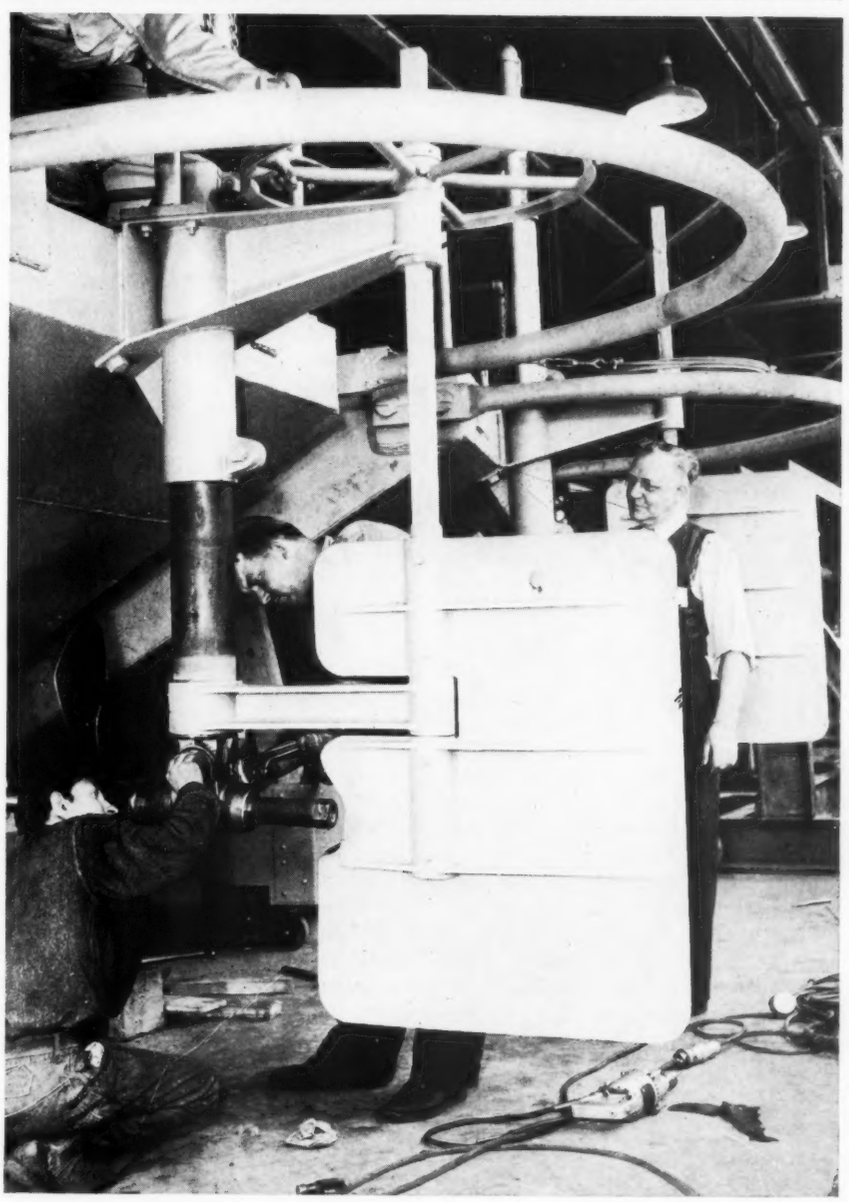
Unit is connected to the cargo carrier by lifting it with a crane, then lowering it so that Z-bars fastened to its forward end match with and slip down over flanges of I-beams fixed on the stern of cargo carrier. Bolting some simple clamps makes marine tractor an integral part of the carrier. Installation can be made in a few minutes with no other tools than an ordinary wrench. Tractor complete, with fuel, weighs about 4 tons.

Pontoon made of welded steel plate houses the power plant. Power is furnished by a standard eight-cylinder Chrysler Royal marine engine, 3¼ in. bore and 4⅞ in. stroke. Reduction gear is 4.48 to 1. At 500 r.p.m. of propeller, the engine develops 108 hp. Three-bladed propeller is 40 in. dia. with 28 in. pitch.

Engine is ordinarily cooled by circulating water taken in and discharged through openings in side of pontoon. An auxiliary arrangement is also provided for use when the craft is operating in muddy streams, whereby cooling water is circulated in a closed system through a pipe coil fastened to the outside of the pontoon.

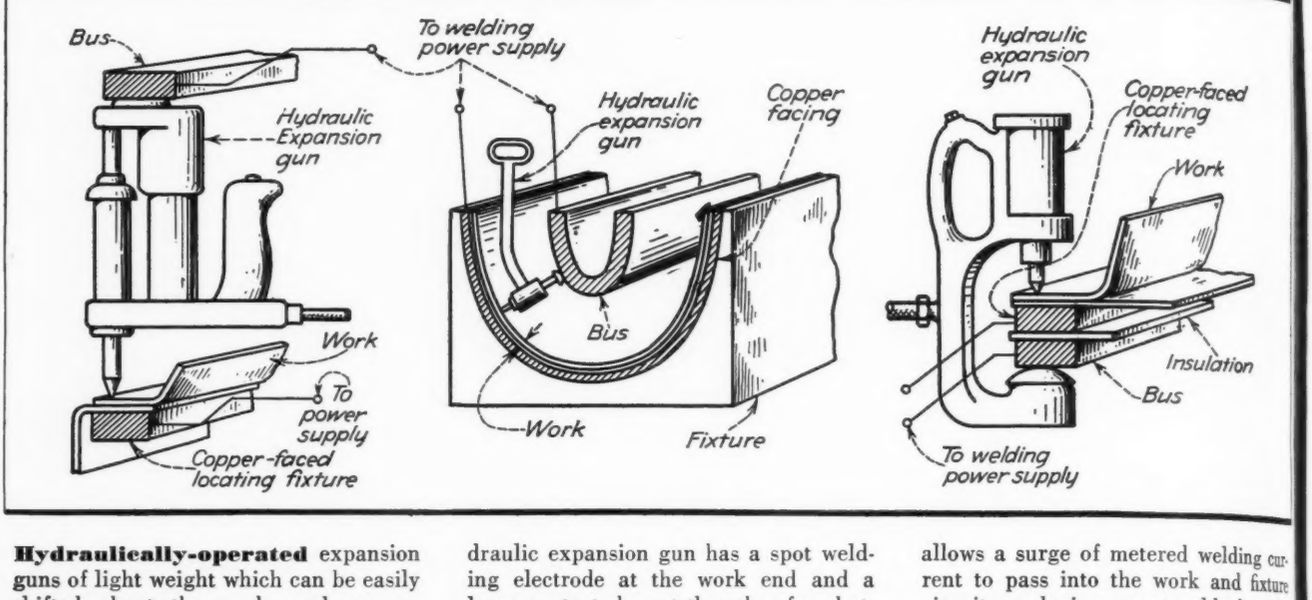
Engine controls, including starter, throttle and reversing gear regulator are placed at the helmsman's station, which is on a platform on the after deck of the tractor. A steel bulkhead protects the crew from head winds, spray, and wash. A high steel railing is also provided for safety. For military or naval use, the control platform can be further protected by an armorplate shield.





Propeller shaft is connected to engine shaft with a universal joint. An outboard propeller shaft bearing aft of the propeller is connected to the lower end of stern post with a pin-joint. Stern post is carried by a tubular structure bolted to the aft end of tractor pontoon. On lower end of stern post is an outrigger arm which carries a bearing in which the rudder shaft turns. By means of a hand chain and fall hung on a framed-pipe deck structure the rudder post and propeller can be moved through a vertical range of 22 in. Thus the propeller can be raised when in shallow water to avoid damage, or when in deep water lowered below the keel level for optimum performance.

FIXTURES WITH EXPANSION GUN SPEEDS WELDING



Hydraulically-operated expansion guns of light weight which can be easily shifted about the work, and copper-faced locating fixtures with insulated bus structures, as developed by E. R. Siefkin of Vega Aircraft Corporation are in use for welding aluminum alloy aircraft parts such as carburetor air scoops, oil cooler scoops, cowl rings, and nested parts.

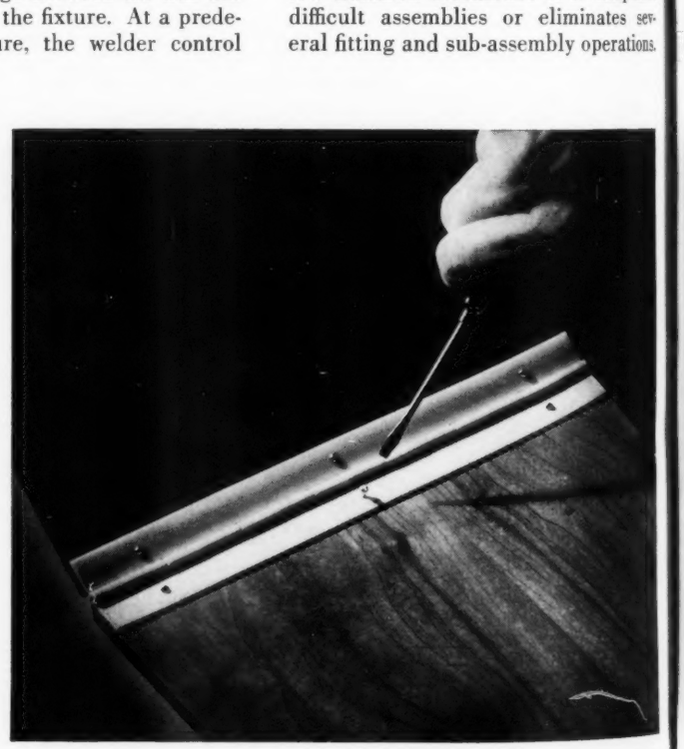
Copper-faced fixtures which support and locate the parts, provide electrical contacts at all points where spot welds are to be made. Insulated bus structures attached to the fixtures are parallel to the contours to be welded. The bus bars back-up the expansion gun and also conduct the welding power from the power supply to the gun. The hydraulic expansion gun has a spot welding electrode at the work end and a large contact shoe at the other for abutting against the bus bar. Only a hydraulic hose and a control cable are attached to the gun, so that it is easy to get around and at the work.

After the parts to be welded have been properly located and clamped in the copper-faced fixture, the expansion gun is placed between the bus bar and the parts assembly. When the control button on the gun is pressed, the welder control applies hydraulic pressure to the cylinder of the gun, causing the gun to expand and form an electrical and mechanical bridge between the bus bar and the work in the fixture. At a predetermined pressure, the welder control allows a surge of metered welding current to pass into the work and fixture circuit, producing a spot weld where the electrode on the gun contacts the work. After the weld is made, the welder control automatically releases the hydraulic pressure, after which the gun retracts and is ready to be moved.

Materials welded by this method are aluminum alloys up to 0.081 in. thick, stainless steels up to 0.125 in. thick, and low carbon steels up to 0.091 in. thick. Primarily a mass production method because of the cost of special copper-faced fixtures, fixture welding may yield an overall saving on only a few hundred assemblies if it simplifies difficult assemblies or eliminates several fitting and sub-assembly operations.

EXTRUDED PLASTIC HINGES SAVE METAL

PIANO-TYPE HINGES OF CELLULOSE ACETATE, extruded in continuous lengths, are being used on airplane tool boxes, oil immersion boxes, radio, map and chart cases. The plastic hinges weigh less than those of metal, an important factor in the design of light-weight portable equipment. As produced by the Plastics Process Company, the extruded plastic hinges can be cut to any desired length. Adhesives, rivets or screws can be used to assemble the hinges to parts made of other materials. The plastic cannot be readily dented, chipped or cracked. It is also rust-proof and dirt-resistant.



Permanent Buckling Strains In Flat Compression Panels

FLETCHER N. PLATT
Structural Design Engineer, Fleetwings, Inc.

An approximate and simplified method for the determination of permanent buckling strains in rectangular flat thin skin panels which are to be loaded in compression. Examples are included to illustrate use of method for both design and test purposes.

IN AIRCRAFT the design of thin walled structures is based upon two primary conditions. These are: the structure must carry applied air loads without permanent deformation, and the structure must support ultimate loads (1.5 times applied loads) without failure.

In some types of aircraft the importance of weight dictates use of thin sheets of metal supported by ribs and stiffeners. This type of construction permits the sheet to carry a portion of the load, and the stiffeners to carry the remainder when the skin has buckled out of action. It is permissible for designers to select a skin thickness that will buckle below the applied loads, provided that the buckles do not remain permanent after applied loads have been sustained.

The investigation of a permanent buckling problem is simplified if strains are considered rather than loads or stresses. After buckling has taken place in a sheet the true stress in the sheet is the algebraic sum of the compression stress and bending stress. The true stress f in lb. per sq. in. can be calculated by the following equation, in which

P = applied load in lb.
A = area of cross section, sq. in.
M = bending moment, in lb.
y = deflection, in.
I = moment of inertia of section, in.^{4}

$$f = P/A \pm \frac{My}{I}$$

where P/A = compression stress

$\frac{My}{I}$ = bending stress

An approximate method for determining the true stress f will be presented for the solution of problems in which the strain applied by the supporting structure is known. The compression stress, P/A, will be omitted in the calculations, since its effect on permanent buckling strains is within the accuracy of the method that will be presented.

In Timoshenko's "Theory of Elastic Stability", the prediction of first buckling strains in sheets has been covered thoroughly, but the prediction of permanent buckling strains has received relatively little study. The complex mathematics involved in calculating the magnitude of permanent buckling strains has probably been the reason for the lack of information on this subject. The approximations presented herewith simplify the problem considerably and yet are accurate enough for most design purposes.

Consider the flat plate shown in Fig. 1 to be t in. thick, to be b in. wide, to be simply supported on four sides, and the side parallel to the load to be a in. long. When the ratio a/b is greater than 0.5 the sides that are not loaded will stiffen the center of panel sufficiently to make the following conservative assumptions. After buckling has occurred the sheet at section $b/2$ will take a form similar to that shown in Fig. 2. The deflection curve is a true sine curve but for simplification of calculations the curve is assumed to be an arc of a circle. For small angles this assumption is justifiable for the same reasons that in the basic theory of beams in bending, the deflection curve of a beam is considered to be the arc of a circle in which the reciprocal of the radius of curvature equals M/EI. The solution of permanent buckling is made in terms of the strain ϵ in. per in. versus the ratio a/t. The stress in the sheet varies over the width b after buckling, but if the stress of the supporting members along the side parallel to the load is known the applied strain can readily be computed.

a = length of sheet parallel with load, in.
r = radius of curvature, in.
θ = central angle of buckled section, deg.
x = chord length of buckled section, in.

$$a = 2\pi r\theta/360 \quad (1)$$

$$\theta/2 = \text{arc sin } x/2r \quad (2)$$

$$\theta = 2 \text{ arc sin } x/2r \quad (2a)$$

Substituting Equation (2a) in Equation (1)

$$a = 4\pi r \text{ (arc sin } x/2r) /360 \quad (3)$$

$$= \pi r \text{ (arc sin } x/2r) /90 \quad (3a)$$

From the theory of the strength of materials,

$$\frac{1}{r} = \frac{M}{EI} \quad (4)$$

Also where

f_y = yield stress of the material in

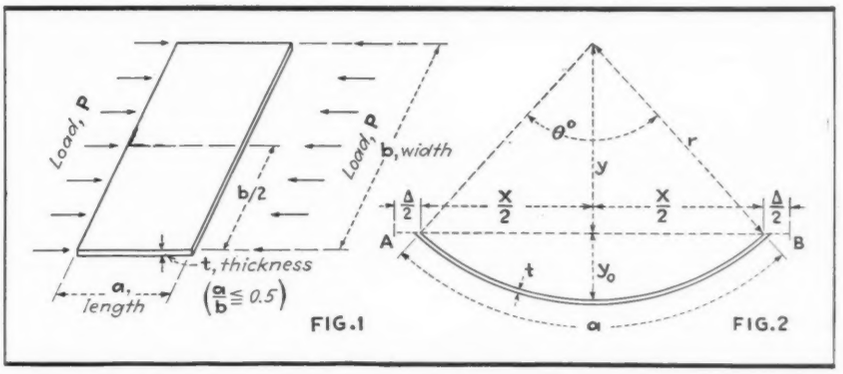


Fig. 1—Thin flat plate, supported on four sides, loaded in compression. Fig. 2—Deflection curve of thin flat sheet loaded in compression is assumed to be an arc of a circle

bending obtained from tests

$c = t/2$ for sheet in bending

$$f_v = \frac{Mc}{I} \tag{5}$$

From Equations (4) and (5)

$$r = \frac{tE}{2f_v} \tag{6}$$

Substituting Equation (6) in Equation (3*a*)

$$a = \frac{\pi tE}{180 f_v} \text{ arc sin} x f_v/tE \tag{7}$$

$$\frac{a}{t} = \frac{\pi E}{180 f_v} \text{ arc sin } x\, f_v/tE \tag{7a}$$

Let

$$C_1 = \frac{\pi E}{180 f_v}, \text{ and } C_2 = \frac{f_v}{E}$$

Then

$$a/t = C_1 \text{ arc sin } \frac{x}{t} C_2 \tag{7b}$$

$$\frac{x}{t} C_2 = \sin \frac{a}{C_1 t} \tag{8}$$

$$x = \frac{t}{C_2} \sin \frac{1}{C_1} \frac{a}{t} \tag{8a}$$

From Fig. 2

Δ = total deflection $= a - x$

$$\epsilon = \frac{\Delta}{a} \tag{9}$$

$$= \frac{a - x}{a} = 1 - \frac{x}{a} \tag{9a}$$

Substituting Equation (8*a*)

$$\epsilon = 1 - \left(\frac{1}{C_2} \cdot \frac{t}{a} \sin \frac{1}{C_1} \frac{a}{t} \right) \tag{10}$$

Tests have been conducted to determine values of f_v for 24ST Dural and 24ST Alclad. Several different gages of material were tested in both directions of grain by bending strips 18 in. by 1 in. around radius blocks. The largest radius at which the specimen would show signs of permanent set was considered the yield radius. (Over the 18 in. strip, $\frac{3}{64}$ in. deflection at the center is considered permanent set.) From the yield radius the value of f_v was calculated from Equations (4) and (5). Results of these tests are

for 24ST Dural,

f_v = 35,000 to 37,000 lb. per sq. in.

for 24ST Alclad,

f_v = 8,000 to 9,000 lb. per sq. in.

The 0.2 percent offset yield point stress of Dural is 40,000 lb. per sq. in. but the actual permanent buckling yield is below this value because the proportional limit of the material is lower.

Alclad sheet is Dural with a thin coat of pure aluminum on each side. The pure aluminum has a 0.2 percent yield stress of 5,000 lb. per sq. in. and prevents the Dural from regaining its original shape after a stress of 8,000 to 9,000 lb. per sq. in. is exceeded. It is therefore of considerable structural advantage to use Dural sheets if permanent buckles are a design factor. Alclad is more corrosion resistant than Dural but Alclad is a necessity only if primer and paint are to be omitted, or if the skin is to be spot-welded.

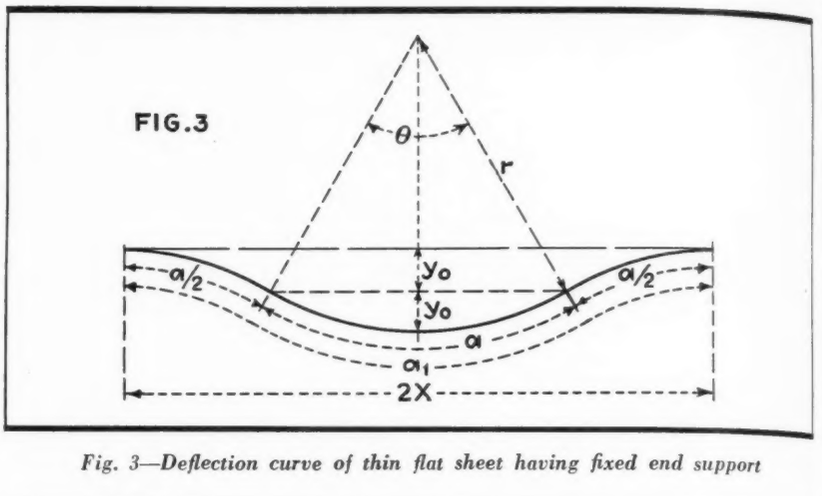


Fig. 3—Deflection curve of thin flat sheet having fixed end support

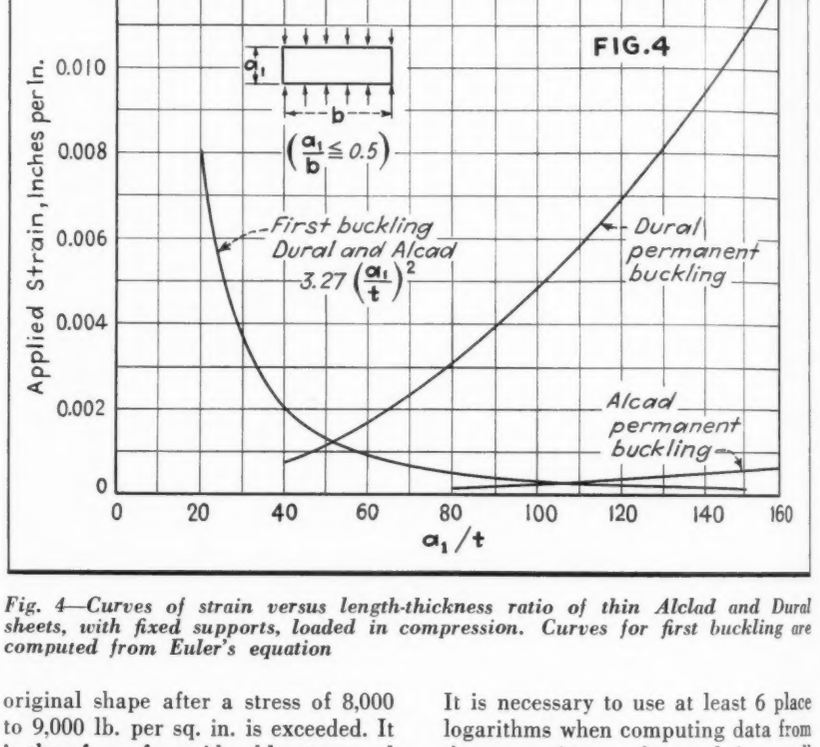


Fig. 4—Curves of strain versus length-thickness ratio of thin Alclad and Dural sheets, with fixed supports, loaded in compression. Curves for first buckling are computed from Euler's equation

Using the lowest test value of f_v, and a modulus of elasticity,

$$E = 10.3 \times 10^6,$$

the following equations are obtained from Equation (10) for strain at permanent buckling,

for 24ST Dural,

$$\epsilon = 1 - \left(294.2857 \frac{t}{a} \sin 0.1946939 \frac{a}{t} \right)$$

for 24ST Alclad,

$$\epsilon = 1 - \left(1{,}287.500 \frac{t}{a} \sin 0.04450147 \frac{a}{t} \right)$$

It is necessary to use at least 6 place logarithms when computing data from these equations as the result is a small difference of two numbers.

The derivation presented is based upon a flat plate simply supported on four sides. In most design problems the loaded side of the panel usually approaches a fixed support. It can be seen from Fig. 3, that a_1 equals $2a$ for fixed supports.

Curves of strain ϵ versus a_1/t are plotted in Fig. 4 for 24ST Dural and 24ST Alclad with fixed supports at the loaded ends. In Fig. 4 a curve is also plotted for first buckling strain ϵ_{bu} versus a/t for panels with fixed ends, obtained by using the Euler equation for f_{bu}

$$f_{bu} = \frac{4\pi^2 E}{(l/\rho)^2} \tag{11}$$

This equation can be stated in the form

$$\epsilon_{bu} = \frac{4\pi^2 t^2}{12 a_1^2} = 3.27 \left(\frac{t}{a_1}\right)^2$$

where

$\epsilon_{bu} = f_{bu}/E$

$l = a_1$, and $\rho = t/\sqrt{12}$, (for rectangular plates)

The Euler equation is applicable in this case rather than the flat plate buckling equation

$$f_{bu} = \frac{K\pi^2 E}{12(1-\mu^2)}\left(\frac{t}{b}\right)^2$$

as it has been assumed that the unloaded sides of the plate give no support. Actually for values of a/b less than 0.5 the two equations are approximately the same.

During static tests of aircraft structures it is desirable to know if buckles in the surface will be permanent, without relieving the load at each increment. The depth y_0 of buckle for simply supported edges can be calculated from

$$y_0 = r - \sqrt{r^2 - a^2/4} \qquad (12)$$

The depth y_1 of buckle for fixed ends can be calculated from

$$y_1 = 2y_0 = 2r - 2\sqrt{r^2 - a_1^2/16} \qquad (13)$$

The distance $2x$ between nodes can be calculated from Equation ($8a$) and the relationship a_1 equals $2a$

$$x = \frac{2t}{C_2} \sin \frac{1}{C_1}\frac{a_1}{2t} \qquad (14)$$

But $2x$ is approximately equal to a_1 for buckles having a radius of curvature in the range considered, so by making this substitution in Equation (13) to obtain the relationship of depth y_1 versus wave length of buckle,

$$y_1 = 2r - 2\sqrt{r^2 - (2x)^2/16} \qquad (15)$$

The radius r is determined from Equation (6) for any particular sheet thickness t. Curves are then plotted as in Figs. 5 and 6 for fixed supports for depth of buckle versus wave length of buckle for various skin gages in 24ST Dural and 24ST Alclad.

These curves can be used to approximate permanent buckling by measuring the depth of buckle of panels during static tests by laying a straight edge over one wave length and measuring the depth of buckle below the straight edge. The wave length should be substituted for the panel length a_1. The use of the buckling curves can be clarified by an example.

A flat rectangular panel has the following dimensions

$a_1 = 5.25$ in.
$b = 12$ in. (loaded side)
$t = 0.064$ (sheet)
$a_1/t = 82$ $\qquad a_1/b = 0.438$

From Fig. 4 the first buckle would occur at a strain of 0.0005 in. per in. If the sheet is Alclad, this buckle will remain permanent as the permanent buckling curve for Alclad is below the first buckle curve. If the sheet is Dural, an applied strain of 0.0032 in. per in. can be applied before buckling becomes permanent.

Assume this same sheet is being tested and a single wave has formed over the length a_1. The depth of the buckle at a certain load (or applied strain) is measured at $\frac{1}{16}$ in. (0.0625 in.). Referring to Fig. 5 for Alclad, it is seen that the buckle will be permanent, as the critical depth of buckle for 0.064 sheet and $2x$ equal to 5.25 in. is 0.04 inches.

Referring to Fig. 6 for Dural, the buckle will not become permanent until a depth of 0.182 in. is reached.

It is desirable to point out again that the methods presented in this article are only approximations and the accuracy of the methods will depend on the nature of the structure considered. The panels have been considered flat and curvature of the sheet will usually lower the permanent buckling strains. Permanent buckling is also affected by the elasticity of the adjacent structure. If this structure is acting at a low stress and a corresponding low strain, permanent buckles may be pulled out of the sheet. But if the adjacent material yields at the same time or before the skin reaches its permanent buckling strain, the buckles will probably remain in the sheet. It has been assumed that the support given along the side which is parallel to the load has no effect on the middle of the panel. If the ratio of a/b is greater than 0.5, this assumption is not valid. All of these conditions must be studied before applying the method presented to a particular structure.

In summation, an approximate method has been presented for the determination of permanent buckling strains of certain flat rectangular panels. Application of the method has been made for both design and test purposes. Other methods of determining permanent buckling strains may be necessary for some structures but, in most types, the method presented will give sufficient information for design of compression panels under applied loads.

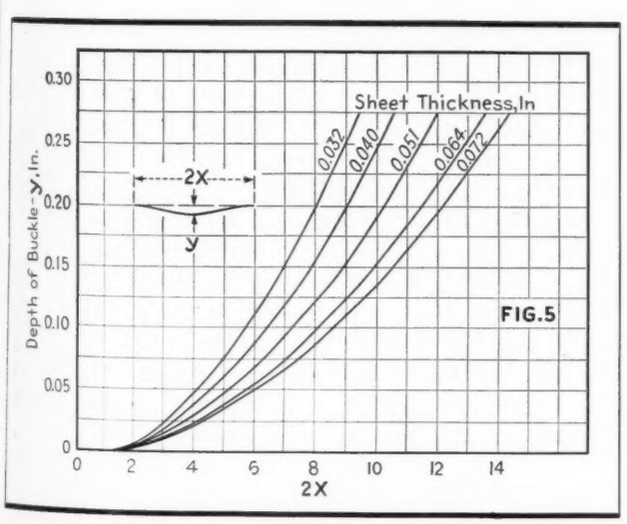


Fig. 5—Curves showing depth at which buckles becomes permanent versus wave length of buckle for various skin gages of 24ST Alclad sheets with fixed support

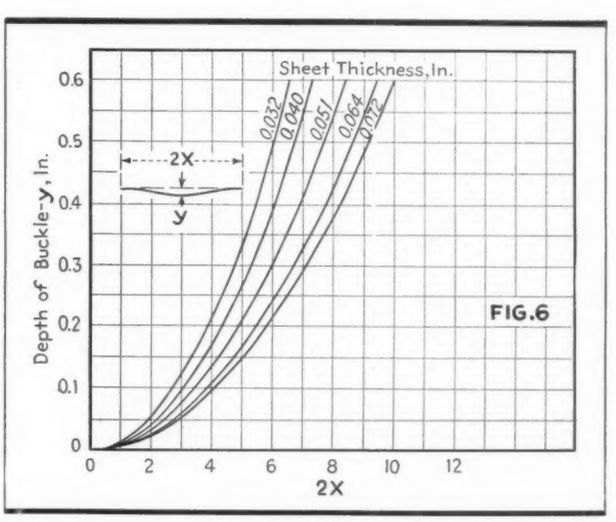


Fig. 6—Curves showing depth at which buckles becomes permanent versus wave length of buckle for various skin gages of 24ST Dural sheets with fixed support

Shrink Fit Tolerances For Various Metals and Needs

A survey of the negative clearances used by leading manufacturers in the design of various types of shrink fits, including data on the shrinkage obtained through chilling.

WHEN a male and female part are to be held together by a friction grip, then a force fit or a shrink fit may be used. When parts are designed for shrink fitting, they have a negative clearance at room temperature. The two parts may be slid together, by heating the female so that it will expand, by contracting the male part through chilling, or by doing both. When the mating parts are again at room temperature, they are gripped together by a force which is related to the negative clearance at that temperature.

This form of fit, termed an interference or shrink fit, is employed for locating parts that are to be held together by some other process such as welding; for assuring positive metal to metal contact; for firm holding fits, and for pre-stressing as in the manufacture of gun barrels.

Table I—Approximate Shrinkage of Rings or Cylinders When Chilled From 70 deg. to —100 deg. F.

Material	In. Shrinkage per In. Dia.
Tool steel	0.0011
Phosphor bronze	0.0016
Aluminum bronze	0.0016
Brass	0.0018
Aluminum	0.00215
Magnesium	0.00225

The shrink fit may be made by one of three methods. Heat may be applied to the female part while the male part is kept at room temperature. This type of fit has been in use for many years, and an example is the heating of steel wagon-rims to be shrink fitted on to the wooden wheel. The current shrink fitting of rims on locomotive wheels dates back to the carriage era. Care must be exercised that the heating will not draw the temper of the metal.

This danger may be avoided by making the fit through chilling the male part. While heat treatment requires access to a furnace and careful temperature control, chilling can be accomplished by portable units which enables a more flexible plant routine. This movable unit may have a refrigerator, or be dependent on dry ice or the vaporization of a liquefied gas. The scale that is formed during heating is avoided when the part is chilled. If dry ice is used as the refrigerant, the material must be handled with care to avoid severe burns, for the solid carbon dioxide becomes a gas at —109.3 deg. F., although the maximum chill in an immersion tank is —96 deg. F. When the chilled part is removed from the cooling unit, in a room containing some moisture in the air, frost will form on the part. For the approximate shrinkage of metal rings see Table I.

According to Dr. Replogle of the Deepfreeze Division, Motor Products Corporation, chilling steels to —100 deg. F. or lower, will convert a certain percentage of austenite to martensite, and thereby increase the hardness and strength of the steel.

While there is a limitation to the point to which a female part may be heated, there is no limitation other than equipment, on how far a male part may be chilled.

When a large differential of temperature is desired, then the female may be heated and the male chilled.

Unfortunately, there are no definite design rules to be employed for shrink fits. All the data available were secured as the result of experimentation at industrial plants and shops. When selecting a negative clearance, too large a shrink should be avoided, as excessive stresses will be established, and plastic flow of metal result. For determination of the stresses established, see "Formulas for Calculating Press Fits in Aluminum Rings," PRODUCT ENGINEERING, page 659, November, 1942.

Many articles are now being shrink fitted. The Wright Aeronautical Corporation has a shrink fit assembly of cylinder head to barrel. The head is an aluminum alloy casting and the barrel is a nitralloy forging. To assemble, the barrel is held at room temperature while the head is heated to 600 deg. F. Threads enable the head

Table II—Recommended Interference Fits for Cast Iron and Steel Bushings in Aluminum at Room Temperature

Bushing		Maximum Operating Temperature of Assembly in Deg. F.					
Outside Diam. In.	Approx. Wall Thickness In.	70	150	200	250	300	350
½	1/16	0.0001 0.0005	0.0004 0.0008	0.0005 0.0009	0.0007 0.0011	0.0009 0.0013	0.0010 0.0014
1	3/32	0.0002 0.0008	0.0007 0.0013	0.0011 0.0017	0.0014 0.0020	0.0017 0.0023	0.0021 0.0027
2	⅛	0.0004 0.0013	0.0015 0.0024	0.0022 0.0031	0.0028 0.0037	0.0035 0.0044	0.0041 0.0050
3	5/32	0.0006 0.0018	0.0022 0.0034	0.0032 0.0044	0.0042 0.0054	0.0052 0.0064	0.0062 0.0074
4	3/16	0.0008 0.0023	0.0030 0.0045	0.0043 0.0058	0.0056 0.0072	0.0070 0.0085	0.0083 0.0098
5	7/32	0.0011 0.0029	0.0038 0.0056	0.0055 0.0073	0.0072 0.0090	0.0089 0.0107	0.0105 0.0123
6	¼	0.0015 0.0036	0.0047 0.0068	0.0066 0.0088	0.0088 0.0109	0.0108 0.0129	0.0128 0.0149

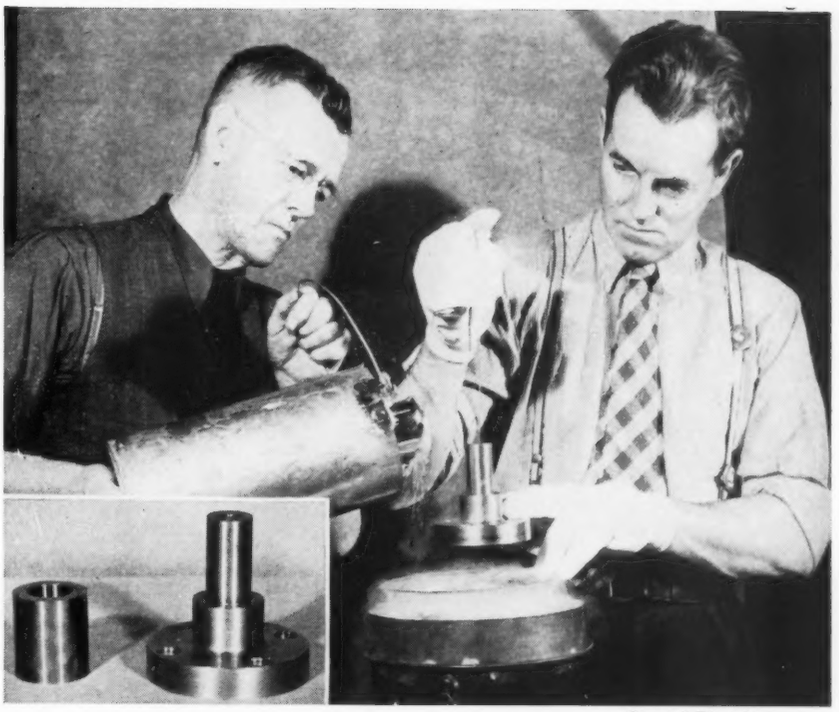
to be screwed on to the barrel, and when the head cools, the fit is so tight, gas cannot escape even at very high pressures. This engine has a normal operating temperature of about 500 deg. F., although when operating in an airplane, it is subjected to sudden cooling by rain or a snow storm.

The crest diameter of the thread on the barrel is 6.6232/6.6260 in., and for the head, 6.4304/6.4332 in. Root diameter on the barrel is 6.4408/6.4436 in., and is 6.611/6.6138 in. on the head.

Another type of interference fit used by this company is the shrinking of a reduction gear on to the propeller shaft, both parts being fabricated from steel forgings. Beside the shrink fit, there is a spline to hold the parts together. Chordal thickness of the involute spline teeth is 0.1953/0.1973 in., and the chordal diameter of the crankshaft teeth is 0.1993/0.2013 in. This results in a maximum negative clearance of 0.006 and 0.002 in. minimum negative clearance.

To assemble, the reduction gear is heated in oil to 400 deg. F., while the crankshaft is kept at room temperature of 70 deg. F. When the assembly is in use, oil having a temperature not over 210 deg. F. passes through the engine.

The Wright plant also shrink fits a steel bearing into a steel crankcase. The ring has a maximum outside diameter of 10.519 in., and the minimum bore of the crankcase is 10.509 in., resulting in a negative clearance of 0.010 in. The crankcase is heated in an electric oven to 275 deg. F., while the ring is chilled to about 23 deg. F. in a refrigerator.



General Electric Company

Pouring liquid nitrogen into a container to shrink a punch part. Units to be assembled are shown in the insert

All the shrink fits used at this plant were developed by trial and error over a period of time, for the Wright engine. They are subject to change should the engines be required to perform under new operating conditions.

A steel-to-steel shrink fit of a different type is used by the Cleveland Pneumatic Tool Company for a low strength shrink fit job. A sleeve is slid over a long exposed shaft, and after the sleeve is positioned on the shaft, and shrink fitted, it is spot welded to the shaft. Press fitting this sleeve into position was not feasible as it would mean the scoring of the exposed part of the shaft, and it would also entail a costly machining job.

The internal diameter of the female or sleeve is 6.000/6.003 in., and the shaft or male is 6.003/6.009 in., making a maximum negative clearance of 0.009 in., or 0.0015 in. per in. dia. To assemble the two parts, the male is sometimes chilled to −40 deg. F., and the female is heated to 400/450 deg. F. If the female were heated above 750 deg. F., there would be a change in the temper of the metal. Sometimes only the male part is chilled and at other times, only the female part is heated, depending upon conditions.

Tables II and III show interference fit allowances followed by the Aluminum Company of America for bronze, cast iron and steel bushings in aluminum. For shrinking a bronze valve seat in aluminum, this company uses a shrink fit of 0.0025 to 0.0035 in. per in. dia. of the ring. In assembling, the valve seat is kept at room temperature while the aluminum is heated to 500 deg. F., or under.

Another fit of this type used by "Alcoa" is the shrinking of a cast aluminum muff blank on a steel barrel, using a shrink fit of 0.0025 to 0.003 in. per in. dia. For a forged aluminum muff, the clearance is from

Table III—Recommended Interference Fits for Bronze Bushings in Aluminum at Room Temperature

Bushing		Maximum Operating Temperature of Assembly in Deg. F.					
Outside Diam. In.	Approx. Wall Thickness In.	70	150	200	250	300	350
½	1/16	0.0001 0.0005	0.0002 0.0006	0.0003 0.0007	0.0003 0.0007	0.0004 0.0008	0.0005 0.0009
1	3/32	0.0002 0.0008	0.0004 0.0010	0.0005 0.0011	0.0006 0.0012	0.0008 0.0014	0.0009 0.0015
2	⅛	0.0004 0.0013	0.0008 0.0017	0.0010 0.0019	0.0013 0.0022	0.0015 0.0024	0.0018 0.0027
3	5/32	0.0006 0.0018	0.0012 0.0024	0.0016 0.0028	0.0019 0.0031	0.0023 0.0035	0.0027 0.0039
4	3/16	0.0008 0.0023	0.0016 0.0031	0.0021 0.0036	0.0026 0.0041	0.0031 0.0046	0.0036 0.0051
5	7/32	0.0011 0.0029	0.0021 0.0039	0.0027 0.0045	0.0033 0.0051	0.0040 0.0058	0.0046 0.0054
6	¼	0.0015 0.0036	0.0027 0.0048	0.0034 0.0055	0.0042 0.0063	0.0049 0.0070	0.0057 0.0078

Table IV—Shrink Fits for Cast Iron Hub on Steel Shaft

Nom. Dia.	Basic Hole	Hole Toler. +	Hole Toler. −	Basic Shaft	Shaft Toler. +	Shaft Toler. −	Allowance Mean.	(Interference) Max.	(Interference) Min.
1/8	0.1250	0.0003	0.0003	0.1253	0.0003	0	0.0004	0.0009	0
1/4	0.2500	0.0003	0.0003	0.2503	0.0005	0	0.0005	0.0011	0
3/8	0.3750	0.0003	0.0003	0.3753	0.0005	0	0.0005	0.0011	0
1/2	0.5000	0.0003	0.0003	0.5003	0.0005	0	0.0005	0.0011	0
5/8	0.6250	0.0005	0.0005	0.6255	0.0005	0	0.0007	0.0015	0
3/4	0.7500	0.0005	0.0005	0.7505	0.0005	0	0.0007	0.0015	0
7/8	0.8750	0.0005	0.0005	0.8755	0.0005	0	0.0007	0.0015	0
1	1.0000	0.0005	0.0005	1.0005	0.0005	0	0.0007	0.0015	0
1 1/8	1.1250	0.0005	0.0005	1.1257	0.0005	0	0.0009	0.0017	0.0002
1 1/4	1.2500	0.0005	0.0005	1.2507	0.0005	0	0.0009	0.0017	0.0002
1 1/2	1.5000	0.0005	0.0005	1.5007	0.0005	0	0.0009	0.0017	0.0002
1 3/4	1.7500	0.0005	0.0005	1.7507	0.0001	0	0.0012	0.0022	0.0002
2	2.0000	0.0005	0.0005	2.0007	0.001	0	0.0012	0.0022	0.0002
2 1/4	2.2500	0.0005	0.0005	2.251	0.001	0	0.0015	0.0025	0.0005
2 1/2	2.5000	0.0005	0.001	2.501	0.001	0	0.0015	0.0030	0.0005
3	3.0000	0.0005	0.001	3.001	0.001	0	0.0015	0.0030	0.0005
3 1/2	3.5000	0.0005	0.001	3.5010	0.0015	0	0.0017	0.0035	0.0005
4	4.0000	0.0005	0.001	4.0015	0.0015	0	0.0022	0.0040	0.0010
4 1/2	4.5000	0.0005	0.001	4.5015	0.0015	0	0.0022	0.0040	0.0010
5	5.0000	0.0005	0.001	5.0020	0.0015	0	0.0027	0.0045	0.0015
6	6.000	0.001	0.001	6.0020	0.0015	0	0.0027	0.0045	0.001
7	7.000	0.001	0.001	7.0030	0.0015	0	0.0037	0.0055	0.002
8	8.000	0.001	0.001	8.0030	0.0015	0	0.0037	0.0055	0.002
9	9.000	0.001	0.001	9.0040	0.0015	0	0.0045	0.0055	0.003
10	10.000	0.001	0.001	10.0040	0.0015	0	0.0045	0.0045	0.003
12	12.000	0.001	0.001	12.005	0.002	0	0.006	0.008	0.004
14	14.000	0.001	0.001	14.006	0.002	0	0.007	0.009	0.005
16	16.000	0.001	0.001	16.007	0.002	0	0.008	0.010	0.006
18	18.000	0.001	0.001	18.008	0.002	0	0.009	0.011	0.007
20	20.000	0.001	0.001	20.009	0.002	0	0.010	0.012	0.008
24	24.000	0.001	0.002	24.011	0.002	0	0.012	0.015	0.010
28	28.000	0.001	0.002	28.0130	0.0025	0	0.014	0.0175	0.012
32	32.000	0.001	0.002	32.0150	0.0025	0	0.016	0.0195	0.014
36	36.000	0.002	0.002	36.017	0.003	0	0.0185	0.022	0.016
40	40.000	0.002	0.002	40.019	0.003	0	0.0205	0.024	0.018
48	48.000	0.002	0.002	48.023	0.003	0	0.0245	0.028	0.022
56	56.000	0.002	0.002	56.027	0.003	0	0.0285	0.032	0.026

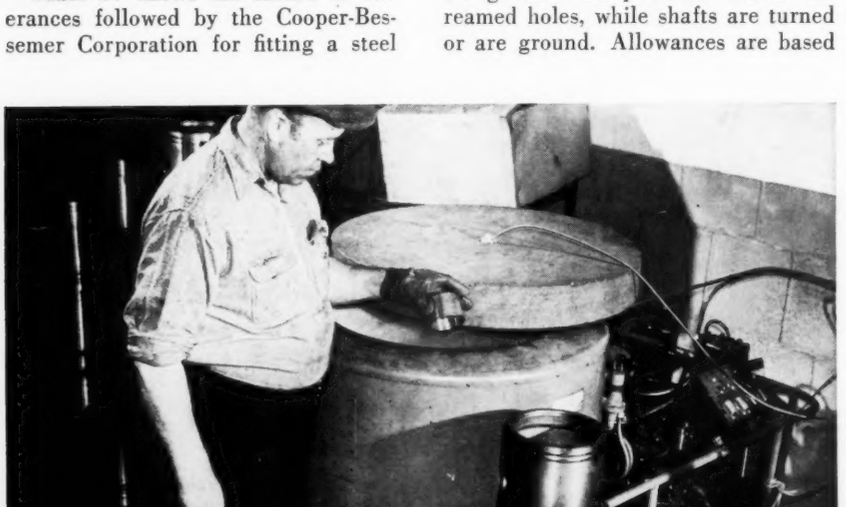
0.0025 to 0.0035 in. per in. dia. The muff is heated to 500 deg. F., and the steel barrel is kept at room temperature.

Table IV shows the shrink fit tolerances followed by the Cooper-Bessemer Corporation for fitting a steel shaft into a cast iron hub. The hole size is considered as basic, and the interference allowance is made on the shaft or male part. Tolerances are for ground and precision bored and reamed holes, while shafts are turned or are ground. Allowances are based on the maximum safe stress for cast iron and may be increased from 1.5 to 2.0 times, for other metals. For sizes between those shown in Table III, take figures for the next smaller size.

Assume that tolerances are desired for a 6 in. dia. shrink fit. The basic shaft diameter, as obtained from Table III, is 6.0020, with tolerances of +0.0015 to −0. For the cast iron hub, the bore is 6.000 ± 0.001. This gives a negative maximum clearance of 0.0045; minimum 0.001; and 0.0027 in. as an average.

While the more usual method for chilling male parts is to place the part in a chest cooled by a refrigerating unit, or through the vaporization of dry ice, liquid nitrogen, which gasifies at a temperature below that of dry ice (−410 deg. F.) is used by the General Electric Company to shrink steel parts in the manufacture of electric apparatus. A negative clearance of 0.0005 to 0.0015 in. per in. dia. is used depending on the nature of parts involved.

These examples and tables of empirical design data show what negative clearances are being used for shrink or interference fits. They should serve only as guides.



Deepfreeze Division, Motor Products Corporation

Bronze wristpin bushing being shrink fitted into a Diesel engine piston. Bushing is shrunk 0.005 in., at a sub-zero temperature; piston is at room temperature

Higher Degree Equations Solved by "Trial and Error"

H. A. BOLZ
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By substituting known values for the unknown in higher degree equations, until an approximate balance is secured, results sufficiently accurate for engineering design are readily obtained. This "trial and error" method of solution is described.

ARE YOU a member of that group of practicing engineers who, because of mathematical rustiness, avoid problems involving higher degree equations? If so, it will be to your advantage to consider a powerful and convenient tool which anyone can apply to the solution of any algebraic equation. The tool is known by the common name of "trial and error."

If, in the process of calculating a design, you should develop the following fourth degree equation: $4x^4 + 2x^3 + 7x + 4 = 0$, how would you solve for x in order to complete your specific design?

In your elementary algebra course you learned that first degree (linear) and second degree (quadratic) equations can be solved exactly. You learned further that third-degree (cubic) equations can be solved exactly by a rather laborious process and that fourth-degree (quartic) equations can be solved exactly only by an extremely tedious process. Fifth (quintic) and higher degree equations are unsolvable so far as exact roots are concerned.

Several methods of obtaining approximate solutions to the higher-degree equations, as indicated in advanced courses are perfectly good, but naturally are difficult to remember unless used frequently.

The "trial and error" method of attack, like all processes applicable to the solution of problems, may be carried out in a logical and orderly fashion or it may be conducted haphazardly by random guessing until an answer is obtained. The latter approach naturally is the longer one. An orderly "trial and error" solution, although considered somewhat undignified by mathematicians, constitutes sound engineering practice. It yields practical results quickly in the case of many complicated problems.

Let us consider first the problem of designing an offset link to satisfy the conditions and proportions indicated in Fig. 1. Under a tensile load F the link would have induced in it a combination of direct tensile and bending stresses expressed by the following relationship:

$$s_b = \frac{F}{A} \pm \frac{M\,c}{I} \qquad (1)$$

where s_b represents the maximum resultant induced stress in lb. per sq.in., F the load in pounds, A the cross-sectional area in square inches, M the bending moment in lb-in., c the distance from the neutral axis to the outer fiber in inches and I the moment of inertia of the section about the neutral axis in in.^{4}. In designing t, the thickness of the web and flange, to withstand a load F of 4,000 pounds with a maximum allowable tensile stress 4,000 lb. per sq.in., the following calculated values are substituted in equation (1):

$$A = 6t^2; \quad I = 8.5t^4; \quad c = 1.5t;$$
$$M = 4{,}000\,(2.5 - 2.5t)$$

to give this expression in terms of t,

$$4{,}000 = \frac{4{,}000}{6t^2} + \frac{4{,}000\,(2.5 - 2.5t)\,(1.5t)}{8.5t^4}$$

This equation simplifies to

$$t^3 + 0.2745t - 0.441 = 0 \qquad (2)$$

The "trial and error" method of attacking an equation of this sort, as well as those of higher degree, leads to a solution in a reasonably short time and requires only simple slide-rule manipulations. A tabular form for carrying out such calculations is neat and orderly, saves time and is easy to check. The first "cut" or "trial" usually may be made by observation. But, whether made as a result of rational observation or by pure guess, succeeding trials will gradually lead to the solution.

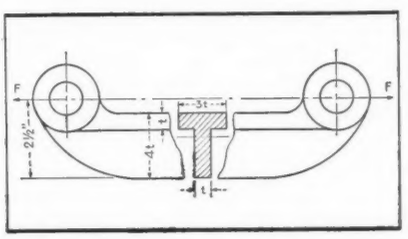


Fig. 1—Thickness of web and flange is to be found

After transferring all terms containing the unknown to one side of the equation as follows, the successive approximations leading to the solution may be carried out for this case as indicated below.

$$t^3 + 0.2745t = 0.441$$

	t in.	t^3	$0.2745t$	$t^3 + 0.2745t$ (= 0.441)
1st trial	1	1.00	0.275	1.275
2nd trial	3/4	0.422	0.206	0.628
3rd trial	5/8	0.245	0.172	0.417
4th trial	11/16	0.325	0.189	0.514

Since an ordinary casting of the type specified in this problem probably would not be held to within one-sixteenth of an inch, $\frac{11}{16}$ in. for t would appear from these calculations to be the answer to our problem. For cases requiring a more nearly exact solution, further trials would be necessary.

The length of time required to obtain a solution to an equation depends in great part upon the designer's judgment in making the first trial.

The "trial and error" method of solving everyday engineering problems of a non-mathematical nature is commonly used where rational analysis is not possible or convenient. It is fully as effective in the solution of mathematical problems. While this process ordinarily is considered to be somewhat undignified as a mathematical method, when applied logically and tempered with intelligent judgment, it constitutes good engineering practice, for it produces workable results quickly.

Powdered Metal Facings For Clutches and Brakes

M. S. ADLER, R. B. AUFMUTH, F. J. LOWEY
Project Engineers, The S. K. Wellman Company

Use of powdered metals in friction elements for clutches and brakes has grown into one of the most important applications of this growing class of materials and products. Their importance and advantages have enabled one manufacturer to build a business devoted exclusively to these units. Hundreds of mixes have been prepared, their frictional properties tested and tabulated, so that it is now possible to produce a clutch or brake facing to suit any type of service. Considerations in the design or use of clutches and brakes so equipped are discussed herewith.

POWDERED METAL friction elements for clutches and brakes, or for other devices, comprise various combinations of copper, iron, lead, zinc, tin, and often other powdered substances such as graphite, silicon carbide, alumina and silica, which are included to obtain desired properties. A typical composition contains 73 Cu, 14 Pb, 7 Sn, and 6 graphite, which differs little from compositions suitable for bearings.

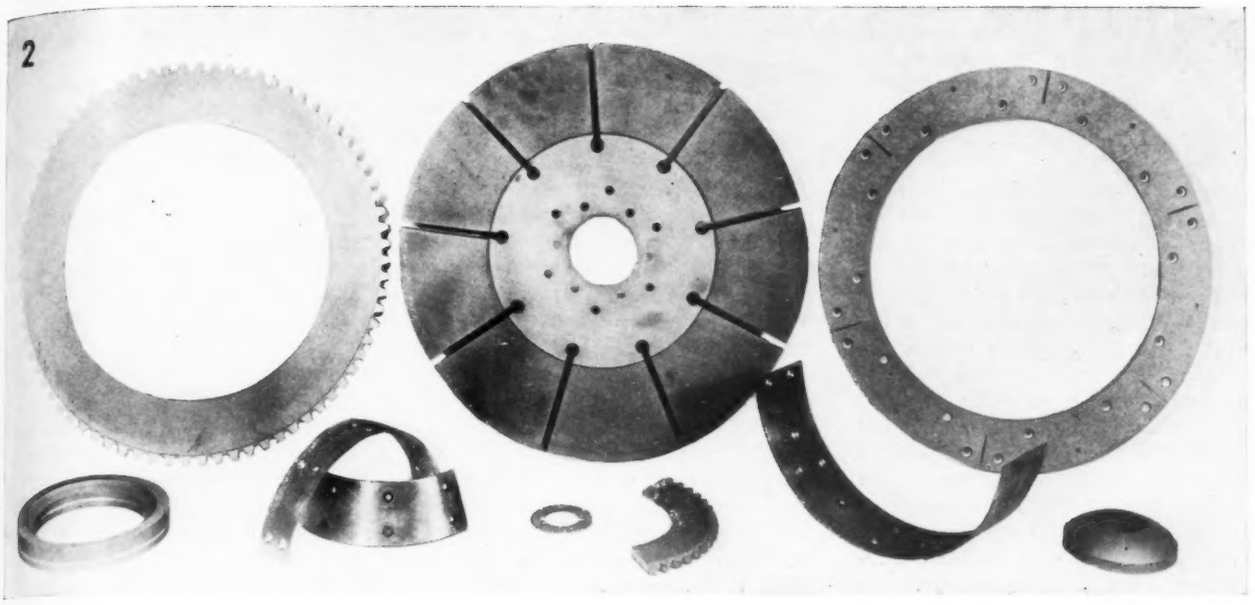
Most friction plates are thin. Because thin sections of sintered powdered metals are relatively weak in tension and shear, a backing plate is provided. The backing material may be steel, stainless steel, copper, bronze, cast iron, or other metal. Low-carbon steels offer enough strength as backing plates for most applications and are most commonly used. Because of the combination of a backing plate with powdered metal friction materials, the term "bimetallic" friction units is used.

Bonding of the friction material to the backing plate is the principal difference between the manufacture of friction units and other products made of powdered metals. This is accomplished simultaneously with the sintering operation for the molded briquets, or "green cookies" as unsintered friction elements are known. This operation is performed under pressure in a reducing atmosphere and at temperatures ranging from 1,250 to 1,650 deg. F. Special furnaces accommodate a considerable number of stacked friction units kept apart by separator plates.

An important preparatory step in the bonding of the facing material to a steel backing is the application of a protective film of copper, nickel, or any other material capable of being electroplated, to the backing. Only 0.0001-in. thick film has proved adequate to prevent surface oxidation in the furnace. This film disappears during the bonding and sintering operation, thereby achieving a direct bond.

The growing use of bimetallic clutch and brake elements is the result of several advantages over common friction materials. The principal advantages are:

1. They perform satisfactorily at temperatures and surface pressures greatly exceeding those of common friction materials.



1 *Various types of riveted-on facings, including internal and external cylindrical and conical forms*

2 *Various types of facings and sandwich type disks, including disks with spline teeth extending beyond the friction material and radial slots for expansion*

3 *External contracting riveted-on type facing. Rivet holes are counterbored and countersunk so that load is carried by steel backing and all the friction material may be worn down to backing without touching rivet heads*

2. They wear longer. The amount of material worn away in absorbing a given amount of energy is low.

3. They do not deteriorate in the presence of oil or water.

4. They withstand severe shock loads.

5. They are not appreciatively affected by arctic cold, tropical heat, nor by variations in atmospheric humidity.

6. They can replace other types of friction materials in existing designs with at most minor changes, and thus improve performance and reduce maintenance.

No Rules Formulated

While it is possible to achieve almost any desired special characteristic by variation in the proportions of constituents, extensive research has not yet revealed any simple formula for determining these proportions. Present practice, therefore, involves the preparation of mixes in the light of all existing knowledge and a thorough trial in a laboratory dynamometer and in the field to determine the characteristics of a given mix. The number of possible mixes is, of course, practically infinite. However, certain broad principles can be applied by engineers in selecting powdered metal friction materials, and in designing clutches and brakes in which they may be used.

Two general types of bimetallic friction elements are being produced. The first consists of a friction material bonded to one side only of a suitable backing strip, which is in turn to be riveted to a clutch or brake plate in the same manner as other common friction materials. The second type consists of a sandwich formed by the application of the friction material to both sides of the backing plate. In this type the backing plate is a clutch plate or disk and is arranged with splines, slots, or other suitable means for positioning the disks in the clutch or brake. When the facing is to be attached by riveting the friction material is counter-bored so that the head of the rivet bears upon the backing strip. The backing strip is countersunk to accommodate flat-head steel rivets of special design.

Rivet-on type facings are made in three forms. The first is a flat type for attachment to a flat plate or disk and may be a disk or segments of a circle. The second is formed to cylindrical or conical shapes for application to external contracting bands or female cones. The third is formed similarly for use in internal expanding drums or on male cones.

The technique of machining bimetallic elements differs from that for other materials and it is generally advisable for the manufacturer of the bimetallic element to drill rivet holes

and do whatever machine work may be required on the friction material, so that the clutch or brake element be supplied ready for installation.

Selection of a backing material involves consideration of the effect of sintering and bonding temperatures upon its physical properties. For example, when sandwich type friction disks are to have spline teeth or lugs, their strength should be calculated on the basis of the material in an annealed condition. Splines or lugs projecting beyond the friction material might be flame or induction hardened but precautions must be taken to avoid heating the friction material itself beyond the oxidizing temperature. In almost every instance the clutch or brake design can be modified to obtain the required strength without resorting to hardening techniques.

The backing may be of any desired thickness and the powdered metal friction material can be made any desired thickness down to 0.010 in. However, it is seldom necessary to make the thickness of the friction material over ¼ in. because of its long wearing qualities.

Operating Temperatures

The maximum operating temperature and unit surface pressures to which bimetallic friction materials can be subjected are high. Temperatures as high as 1,000 deg. F. and surface pressures up to 1,000 lb. per sq.in. have been reached in service in some instances. The upper limits vary with each mix, however, and depend upon many factors, such as frequency and duration of engagements, surface velocities, surface pressure, amount of work per unit of surface, and heat dissipation characteristics of the clutch or brake. Experience is necessary in estimating this maximum in a specific design and application.

Because of the higher heat conductivity of bimetallic friction materials as compared to other common friction materials, there is usually a considerably more rapid removal of heat from the contracting surfaces. Because of low heat transfer coefficient in other common materials, most of the heat generated passes out through the opposing surface. Contrasting with this, a bimetallic surface conducts a substantial portion of the total heat away from the contacting surfaces. Consequently, all other factors being equal, the mechanism having a bimetallic friction material will have minimum temperatures on the contacting surfaces. In addition, the opposing surface will have less tendency to heat check and will have a longer useful life.

Sandwich type facings have a further advantage in this respect in that the elimination of air space, however minute, between the friction facing and the part to which it is riveted means a substantially higher rate of heat transfer away from the frictional material.

In instances where lack of space, weight limitation, or like considerations force reduction in total friction surface, thus maximizing pressures and temperatures, it is well to consider a design permitting sandwich type facings because of their higher heat transfer characteristics. The sandwich type facings are also advised for service where high speeds may develop centrifugal forces sufficient to shear rivets.

"Wet" Clutches and Brakes

While the presence of oil does not permanently affect bimetallic friction materials, it does, of course, lubricate the rubbing surfaces until the oil is removed by the effect of pressure, temperature, absorption into the porous metallic friction surface or by mechanical means such as grooves or slots in the surface of either the bimetallic material or the opposing surface. Such grooves are sometimes highly desirable as means of speeding the breaking up of an oil film between contacting surfaces. The kind of grooving depends upon design and conditions of operation.

A clutch or brake may be run in oil if the loads to be imposed are high, so that the oil serves to cool the assembly. The design of a machine may be greatly simplified in some instances by installing the clutch or brake in the same chamber or compartment that houses another mechanism that runs in oil. However, it is preferable that a "wet" clutch be arranged so that it has its own oil supply.

The temperature range developed in operation, which is the greatest single factor affecting the coefficient of friction, does not produce sufficient variation in the coefficient of the friction element to interfere with proper or consistent operation of the clutch or brake. Coefficient of friction is also affected by the relative velocities of the opposing surfaces and the pressures upon them, partially at least because these factors affect surface temperature.

Care should be taken to differentiate between applications involving static or break away coefficient and dynamic coefficient. For example, in a safety clutch, or a tension control device that is designed to hold until a certain torque or tension is reached and then slip, the point at which initial slip occurs is governed by the static coefficient while continuing slip is governed by the dynamic coefficient.

No frictional data are given here because wide variation in mixes make such data impractical. The present range of mixes have dynamic coefficients, as determined by dynanometer tests with wet or dry surfaces, from 0.05 to 0.5. There is a corresponding wide variation in static coefficients. There is also no fixed percentage relationship between static and dynamic coefficients nor consistent degree of change in coefficient with change in temperature among various mixes.

Consideration must be given also to the characteristics of the opposing surfaces. Various materials that are commonly used, such as steel and cast iron, differ as to the temperature they can endure. Other conditions being equal, this temperature varies with the coefficient of friction.

Table I—Standard Rivet Sizes
For Bimetallic Brake and Clutch Facings

Rivet Size	Body Size In.	Head Size In.	Min. Dist. From Edge In.
D	1/4	1/2	5/8
C	3/16	3/8	1/2
B	3/16	5/16	3/8
L	5/32	5/16	3/8

Table II—Size of Blocks
For Flexible Contracting Bands

Diameter of Band In.	Length of Block In.
6 to 12	1
12½ to 16	2
16½ to 20	2½
20½ to 30	3
30½ to 36	4

Rivet Arrangement

Rivet arrangement for bimetallic facings that replace other type facings generally need not be changed. However, care should be taken not to locate a rivet hole less than ⅜ to ⅝ in. from any edge of a facing, depending upon the size of rivet used. As a general rule, at least one rivet for every 4 sq.in. of friction surface is recommended. Also the maximum spacing between rivets is 3½ in. and rivets should be placed at a maximum of

3/4 to 1 in. from the leading and trailing edges of friction segments.

Only steel rivets are recommended, and they are set with a "roll clinch," never a "star clinch," so as to minimize the possibility of small loosened pieces injuring working surfaces. It should be noted that the steel backing member rests against a metal carrier or shoe, the combination of which has a much lower coefficient of friction than the friction working surface. The rivets, therefore, must carry the remainder of the friction force, which may be considerable, as shear stress. Four rivet sizes take care of the majority of applications. They are designated in Table I.

When the steel backing is at least 1/8 in. thick and the segment width allows their use, size D rivets are used. Size C rivets are used generally instead of size D for narrow heavy backed applications and for the wider, thinner-backed job. Size L rivets are used on narrow bands where the backing thickness is 1/16 in. or less and the friction material 1/16 in. or less. Size B rivets are used instead of size L when the backing and friction material are thicker than 1/16 inch. Generally speaking, it is better to use a greater number of small rivets than fewer large rivets. Rivets lengths are available in increments of 1/16 in. Total length is determined by adding thicknesses of backing and carrier plate plus a clinching allowance of 3/16 in. for size D rivets or 1/8 in. for the C, B and L sizes.

Welding, brazing, soldering or screws may also be used to fasten friction segments in place. Care must be exercised when welding, brazing or soldering to prevent the heat from destroying frictional properties of the facing. Tack welding is preferred so that heat can be kept in a small area and, if damage is done, only this small area is affected. Often it is advisable to extend the steel backing beyond the facing in order to keep heat away from it. Soldering may be used wherever operating conditions are such that the generated heat will not melt the solder. Countersunk screws are convenient for pieces that have to be removed often, but there is always a risk that screws may vibrate loose and damage the facing. Rivets are preferable for replaceable parts.

Sometimes it is possible to bond the facing directly to the carrier plate or shoe. This is advantageous because a welded connection conducts heat better than a riveted connection. Then too, the pieces are stronger because there are no rivet holes. This construction is usually limited to disk type carrier plates that are not affected by brazing temperatures and that can be stacked in the brazing furnace. However, if production quantities are sufficient to warrant the set-up, this fabrication method may be employed on various shapes, such as cones, for example.

Factors to be Considered in Designing Mechanisms With Bimetallic Friction Materials

1. Type of service
2. Type of design—disk, shoe, band or cone—internal expanding or external contracting
3. Dimensions of mechanism
4. Kind of material against which friction surface will rub
5. Kind of material to which friction material will be bonded or attached
6. Pressure obtainable on friction surface
7. Type of mechanism applying pressure—springs, levers, cams, hydraulic piston
8. Relative surface velocity or engaging surfaces
9. Power to be transmitted or absorbed
10. Running conditions—wet or dry. If wet, kind of fluid and maximum operating temperature
11. Type of operation—frequency and time cycle

Flexible Band Elements

Although powdered metal facings are rigid materials they can be used on flexible, external contracting bands by application of several individual blocks. These are bent to shape from flat pieces after molding, sintering and brazing. Sizes of these blocks are specified in Table II.

Standard widths of these blocks start at 1½ in. and increase in ¼-in. increments. Standard thicknesses of friction material plus steel start at 1/8 in. and increase by increments of 1/32 in. to ½ in. maximum. Space should be left between each block to allow for thermal expansion and permit full flexibility of the band assembly.

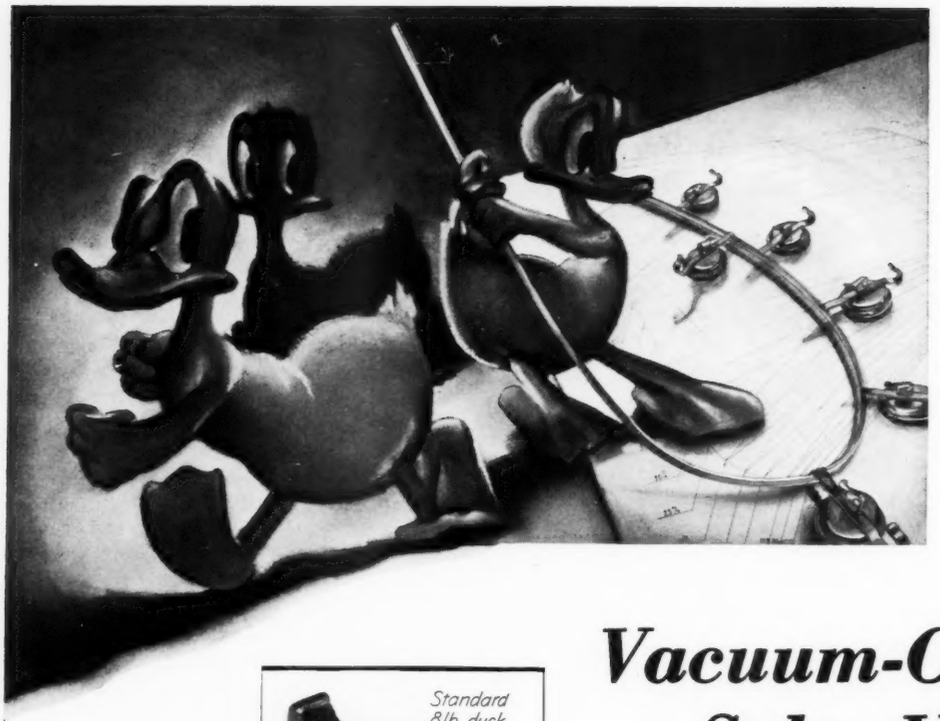
In rigid curved shoe applications, the least number of segments necessary are used, but any curved friction surface over 180 deg. requires at least two segments. An advantage of segmentation is that the space between segments allows for expansion of the friction material as the operating temperature rises, without buckling or stressing and straining accompanying parts. In large area, heavy duty clutch and brake applications, segmentation is not only desirable, but a necessity to absorb thermal expansion. In all instances, 1/8 in. minimum space should be allowed between segments.

Present facilities allow the manufacture of friction material in one piece up to a 36-in. dia. circle or a strip 18 in. long by 12 in. wide. Up to and including ¼ in. overall thickness, 1/16 in. thick material is used. From ¼ to ½ in. overall thickness, the backing material is 1/8 in. thick.

A recent development that has produced revolutionary results in some instances is the use of bimetallic friction materials working against each other in disk type clutches or brakes. This permits even greater flexibility in the friction characteristics than can be produced by variation in content of the mixes. Also, since some powdered metal friction materials are exceedingly durable and wear resistant, higher energy absorption and higher frictional coefficients than would otherwise be possible can be obtained. Similar advantages can often be obtained in band and cone applications.

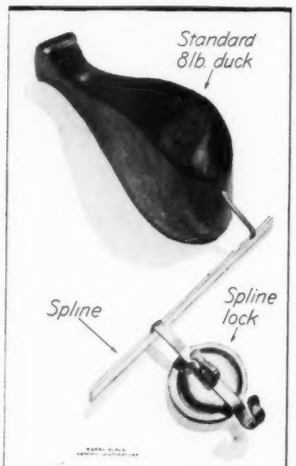
In sandwich type facings, the minimum recommended thickness of each friction surface is 1/64 in. The thickness of backing material is dictated generally by the physical requirements of the clutch or brake design. An important consideration, however, is that the design be one that is easy and economical to manufacture. For example, if a steel core is less than 1/32 in. thick, difficulty may be experienced in producing the desired flatness. Also, clearances in a clutch or brake design should allow for 0.005 in. minimum runout per bimetallic friction surface on sandwich disks up to 6 in. dia., and proportionately greater out of flatness for larger diameter. Not more than 1/8 in. maximum thickness of friction surface per face on sandwich type disks is also a recommended practice. There are some instances where a steel backing is not necessary, as in friction drives where the friction disk is floated without being rigidly attached to mating pieces. These disks may now be made as thin as 0.010 in.

Heavy stamping and forming presses were among the first applications of bimetallic friction material. It has now been used several years in the clutches of earth moving vehicles, trucks, tractors, agricultural machinery, and in aircraft brakes. Present wartime uses include aircraft supercharger clutches, retractable landing gear clutches, and also as a bearing material in tanks, scout cars, and trucks, as well as in their brakes.



Variation developed at Fleetwings, but found unnecessary, consists of screw thread which allows minor adjustments after spline is in place

Vacuum-Cup Locks Solve Vertical Lofting Problem



One end of metal strip holds spline in place and hook on other end is used for lifting holder. Toggle clamp exhausts air to form vacuum which holds lock in place

Because of crowded conditions in the lofting department of Fleetwings, Inc., it was desired to save space by changing the boards from horizontal to vertical positions. However, conventional lead ducks can be used only on horizontal boards. Efforts to find a suitable spline holder for vertical boards resulted in the use of modified vacuum-cup coat hangers.

LEAD DUCKS have been chased out of the lofting department of Fleetwings, Inc., by a small vacuum-cup spline-locking device that simplifies the problem of vertical lofting. Crowded conditions in the department made vertical lofting very desirable but there was no way to hold the splines in place on a vertical lofting board. The heavy lead ducks, weighing about 8 lb. each, were naturally ineffective on inclined or vertical boards.

The only answer to the problem seemed to be a holding device which would keep splines in place on a vertical plane. Much ingenuity went into the efforts to make such a device, but the most satisfactory answer was a modification of the vacuum-cup coat hangers sold for use on automobile windows. These could be purchased for 19 cents each, weigh only 1½ oz. apiece and can be quickly and securely fastened to surfaces, including metal sheets, without scratching them.

Attached to the outside of the rubber suction cup is a metal strip which has one end bent over to engage the slotted edge of the spline. The other end of this strip is curved to form a hook. Formerly, this hook was what held the coat hanger but for spline locks it is used for lifting the lock when the spline is moved. The spline lock is pressed firmly in place with the thumb and is then locked with a toggle clamp which exhausts nearly all the air from the inside of the cup. The vacuum created thereby is strong enough to keep the spline lock in position for all ordinary lofting work.

An improvement on this basic device was worked out by Fleetwings personnel, although it is not used at the present time because it is not needed. This is a screw adjustment built into the spline-holding end of the metal strip so that minor adjustments in the position of the spline can be made after the locks have been fastened in place. An accompanying illustration shows this arrangement for the benefit of those whose lofting work may entail such adjustments.

Although cost and availability of a spline-holding device for vertical lofting were secondary to the efforts to improve working space, it was found that considerable money was saved with the vacuum-cup spline lock as compared with the lead ducks used in horizontal lofting and which cost about $5 each. With the increasing shortage of metals it was becoming more difficult to obtain lead ducks. The vacuum-type coat hangers could be purchased in numerous stores, while the supply lasted. Thus, much lower cost and improved availability were unexpected advantages.

New Series of Thermosetting Materials Covers Wide Range

Tests of many formulations of a new line of synthetic resins developed by the Columbia Chemical Division of the Pittsburgh Plate Glass Company indicate that the series has a wide range in reactivity, hardness, strength, flexibility and resistance to deterioration. Variations of these properties are made by adjusting the chemical structure of the molecules of the monomer, rather than by adding plasticizers. Of the numerous possible formulations in the series, the 39th has been chosen for concentrated commercial development because its properties, as described in this article, are believed to be widest in demand.

As a broad family of numerous different formulations, the new line of synthetic resins developed by the Columbia Chemical Division of the Pittsburgh Plate Glass Company consists of chemical compounds which show promise as colorless, transparent, thermosetting materials. The individual members of the series are all chemical entities which, for the sake of simplicity, are designated by numbers. The many formulations which have been prepared and tested differ from each other in specific properties; the group covering a wide range in reactivity, hardness, strength, flexibility, and general resistance to deteriorating influences. Variations of these properties are made by adjusting the chemical structure of the molecules of the resin monomer, rather than by adding plasticizers. Commercial development is, for the present, being concentrated on what is called C.R. 39 because it possesses general properties which are believed to be widest in demand.

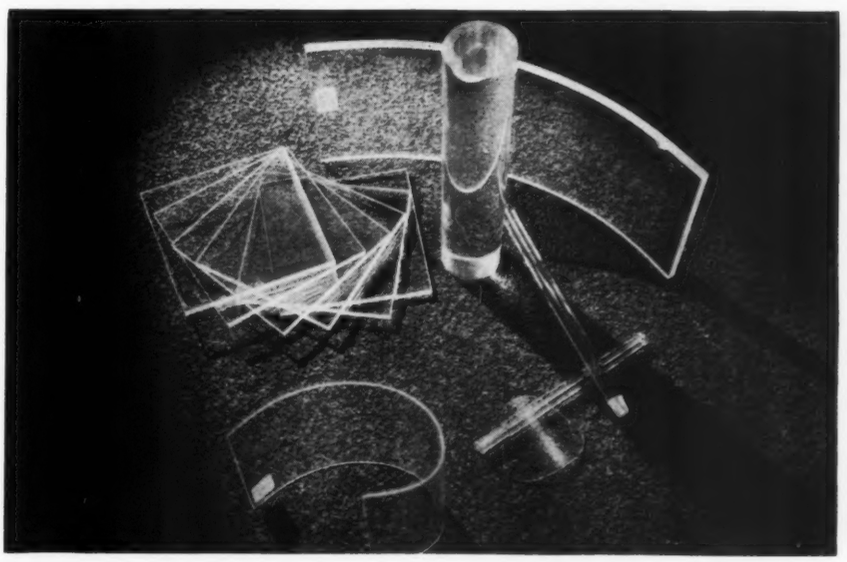
Monomeric C.R. 39 is a clear, colorless liquid of low viscosity containing only carbon, hydrogen, and oxygen. It is stable at ordinary temperatures but upon heating in the presence of a catalyst, such as benzoyl peroxide, it passes through an induction period, then gradually increases in viscosity and gels. Upon further heating the gel hardens and finally becomes a solid that is strong, hard, insoluble, infusible, crystal clear, colorless to slightly yellow. The monomer is thus converted into a hardened resin by a simple polymerization process without the evolution of water, ammonia or any other byproduct. This, together with the inherently low volatility of the monomer, makes low-pressure molding of these resins possible.

Pure C.R. 39 is cast-polymerized, under suitable conditions, into transparent sheets having certain outstanding characteristics. Compared with other transparent plastics, these sheets will not craze when held under stress, are highly resistant to chemicals and solvents, have increased mar and abrasion resistance and have greater resistance to distortion under heat. Weight, strength, shock resistance and ease of forming into bent shapes is comparable with other transparent resins. Cast C.R. 39 sheets burn at about one third the rate of the methacrylates. While C.R. 39 sheets are extraordinarily clear and weather resistant, they yellow slightly upon prolonged exposure to ultra-violet light. This small discoloration does not substantially decrease clarity or light transmission, and will probably soon be eliminated completely.

While sheets of C.R. 39 are somewhat more brittle than corresponding methacrylate sheets at room temperature, they are actually less brittle at temperatures of −40 deg. F. to −70 deg. F. In bursting strength, breaking strength and shock resistance, C.R. 39 sheets compare favorably with the methacrylates.

Pendulum type impact tests conducted in the Columbia Chemical laboratory show that transparent C.R. 39 has substantially the same strength as the methacrylates with notched specimens, but lower strength when unnotched bars are used. Other laboratories have reported that C. R. 39 is somewhat lower than the methacrylates with notched specimens. This may be due, in part, to Columbia's greater familiarity with the machining characteristics of the material.

As a photoelastic material C.R. 39 is believed to be excellent. It does not exhibit any optical creep up to nearly the ultimate stress of the material. The optical sensitivity, 86.6 lb. per sq.in. per fringe per in. thickness, compares well with other photoelastic



Bent and flat sheets, rods and tubes can be made of C.R. 39

Properties of Transparent Cast Sheet Polymer

	C.R. 39	Cast Methacrylate	Plate Glass
Specific gravity	1.32	1.19	2.5
Refractive index	1.505	1.49	1.52
Hardness:			
Knoop	15–18	18–20	approx.
Barcol impressor	28–31		400
Rockwell — M scale	*92–94	*85–105	
H scale	*68	*60–65	
Cold flow:			
Barcol impressor	5–9	13	none
Plastic yield:			
Room temperature, in.	*0.006	*0.005	none
50° C., in.	*0.022	*0.075	none
Abrasion resistance:			
Rotary	20–30	1	500
Falling emery:			
Methacrylate	8–10	1	10
Glass	0.8–1.2	0.1–0.15	1
Flexural strength, lb./sq. in. (a):			
50° C. (122° F.)	5,000–6,000	9,000–11,000	6,500
25° C. (77° F.)	8,000–10,000	13,000–15,000	6,500
−10° C. (14° F.)	13,000–15,000	13,000–17,000	6,500
Modulus of elasticity in flexure, lb./sq. in x 10^5:			
50° C. (122° F.)	1.6–2.0	2.5–3.0	100–110
25° C. (77° F.)	2.8–3.5	3.7–4.5	100–110
−10° C. (14° F.)	4.3–4.6	4.0–4.6	100–110
Deflection at break in flexural test, mils.:			
50° C. (122° F.)	200–250	Cold Flow	0.6
25° C. (77° F.)	200–250	250–400	0.6
−10° C. (14° F.)	160–180	160–200	0.6

	C.R. 39	Cast Methacrylate	Plate Glass
Tensile strength, lb./sq. in., 25° C. (b)	6,000	7,500	6,500
Impact strength, ft. lb./in., 25° C. (c):			
Izod, notched	0.4–0.5	about 0.5	
Charpy, notched	0.4–0.5	0.5–0.55	
Izod, unnotched	2–3	about 5.0	
Charpy, unnotched	5–6	about 7.5	
Break limits, free fall in ft.:			
Flat specimens −70° F.	42	18	
−40° F.	42	21	
0° F.	45	21	
32° F.	36	18	
70° F.	33	18	
120° F.	18	12	
Curved specimens −70° F.	39	26	
−40° F.	45	21	
0° F.	36	21	
32° F.	33	24	
70° F.	42	21	
120° F.	21	18	
Thermal expansion, linear coefficient/deg. C., x 10^{-5}:			
−40° C. to −10° C.	7.2	6.8	0.8
−10° C. to 25° C.	8.9	8.1	0.8
25° C. to 50° C.	10.9	9.8	0.8
Thermal conductivity (d):			
Cal./sec./sq. cm./deg. C./cm. thickness	*5x10^{-4}	*4x10^{-4}	23x10^{-4}
B.t.u./sq. ft./deg. F. hr./in. thickness	*1.45	*1.16	6.67
Heat distortion:			
10 mils distortion, deg. C.	56–68	68	
Distortion at 130° C., mils	35–70	Fluid	

materials and the fringes are more distinct.

In machining operations, such as sawing, turning and drilling, the greater brittleness of C.R. 39 at room temperatures is noticeable. When this is taken into account and suitable tools and methods are used, machining can be done without difficulty. The infusible character of C.R. 39 greatly facilitates operations in which heat is developed, such as sawing, sanding, grinding, polishing, and buffing. These may be done at high speeds without coolants and without the tendency to drag, fuse or gum that is sometimes encountered in the methacrylates.

Fully cured sheets of C. R. 39 can be formed by heat to fairly severe simple curvatures, and moderate compound curvatures, but they cannot be subjected to deep draws over large areas. Conventional plastic forming equipment is used. The sheets show little tendency to distort or to develop surface defects in the heating and forming operations and they are not easily damaged by overheating in the oven. In some cases, where exceptional form stability is required, it may be desirable to form cast sheets while they are in an undercured, flexible condition and to complete their curing in the mold. This procedure consumes more time but yields products which retain their full curvature on aging, even though not confined in frames.

Because Columbia Resins cure without evolution of any volative by-products, and because they exist as liquids of low vicosity which have high penetrating power, requiring no solvents or diluents, they offer interesting possibilities in the field of laminating. Base materials, such as fabrics, felts, papers and wood can be saturated with monomeric Columbia Resins containing a suitable catalyst and cured into laminated board by moderate heating with the application of no more pressure than is required to hold the layers in intimate contact with each other. This pressure ranges from 0.01 to 10.0 lb. per sq. in., but for most applications is from 1 to 2 lb. per sq. in.

Since the Columbia Resins are transparent, substantially colorless and highly resistant to wear, abrasion and attack by chemicals and weather, they are believed to offer interesting possibilities in decorative laminates. It is clear, however, that the monomeric liquid nature of these materials will necessitate for their use the development of special methods different from those used in working with conventional laminating varnishes. Fabrics can be impregnated by simply brushing the monomer either to successive layers or onto the assembled laminate of several thicknesses.

The principal precaution to be observed in laminating is the elimination of air bubbles as completely as possible from all interfaces. Flat laminated sheets can be cured between plates of glass, metal or plastic with no more pressure than the weight of the top plate. Curved shapes can be made either by bend-

Properties of Transparent Cast Sheet Polymer (*continued*)

	C.R. 39	Cast Methacrylate	Plate Glass
Maximum recommended operating temperature, no load:			
Continuous service, deg. C.	80 (176° F.)	70 (158° F.)	
Intermittent (1 hr. duration) deg. C.	150 (320° F.)	80 (176° F.)	
Burning rate, 1/8-in. sheet, in. per min. (e)	0.35	1.1	None
Warpage after 48 hr. at 60° C., in. (f)	None	None	None
Light transmission before aging:			
White, percent	95–96	96	
Blue, percent	90–91	92	
Haze before aging	1–2	1–2	
Light transmission after aging:			
White, percent	94–95	96	
Blue, percent	77–82	89	
Haze after aging	1–2	1–2	
Water absorption:			
Percent, Navy test, (g)	0.2	0.2	
Percent, A.S.T.M. test, (h)	0.2–0.4	0.3	
Power factor:			
At 10^3 cycles	*0.0123		
At 10^6 cycles	*0.0536		
Dielectric constant:			
At 10^3 cycles	*3.92		
At 10^6 cycles	*3.74		
Dielectric loss:			
At 10^3 cycles	*0.0482		
At 10^6 cycles	*0.20		
Dielectric strength:			
Short time, volts/mil	*354		
Step by step, volts/mil	*290		

	C.R. 39	Cast Methacrylate
Resistance to chemical reagents, gain in weight after 7 days immersion, percent, (i) :		
Distilled water	0.8	0.7
30 percent sulfuric acid	0.5	0.3
3 percent sulfuric acid	0.7	0.6
10 percent nitric acid	0.7	0.5
10 percent hydrochloric acid	0.6	0.5
10 percent ammonia	1.1	0.6
10 percent sodium hydroxide	0.1	0.5
1 percent sodium hydroxide	0.7	0.6
2 percent sodium carbonate	0.8	0.6
1 percent sodium chloride	0.65	0.5
3 percent hydrogen peroxide	0.9	0.7
95 percent ethyl alcohol	0.3	11.0
50 percent ethyl alcohol	0.2	3.4
Acetone	1.4	Soluble
Ethyl acetate	0.7	Soluble
Carbon tetrachloride	0.0	−2.4
Chloroform	1.6	Soluble
5 percent acetic acid	0.8	0.7
Gasoline	0.02	0.0
Oleic acid	0.3	0.2
Benzene	0.2	Soluble
Toluene	0.2	Soluble

* Data determined by independent laboratories
(a) A.S.T.M. test D651-41T
(b) A.S.T.M. test D638-41T
(c) A.S.T.M. test D256-38
(d) Cenco-Fitch apparatus used
(e) Navy Aeronautical Specification P-41C, Sec. F-3a.
(f) Navy Aeronautical Specification P-41C, Sec. F-3i.
(g) Navy Aeronautical Specification P-41C, Sec. F-3j.
(h) A.S.T.M. test D570-40T
(i) A.S.T.M. test D543-41T

ing flat laminates according to the technique employed in shaping clear sheets or by curing the original laminate in the desired shape. The latter method is preferable, if form stability is required and if no means is available for restraining the slight tendency of bent sheets to spring back to their original flat form.

For laminating shaped objects inexpensive molds of plaster, papier maché, cardboard, sheet metal, concrete, cast metal, wood, glass or combinations thereof can be used. The slight pressure needed to hold the plies in intimate contact with one another can be applied by screw clamping, wrapping tightly with dry fabrics, applying bags filled with shot as weights, wrapping the cellophane covered laminate with rubber tape under slight tension, use of rubber bags either inside a female form or as envelopes around a male form, or clamping together two rigid mold parts, one of which is cushioned by sponge rubber or some other means. Best results are obtained when one of the mold walls is rigid and the other flexible to allow for such things as irregularities in section and overlapping of the fabric layers.

Fully cured laminated sheets can be cemented together with monomeric Columbia Resins if the areas to be bonded are thoroughly roughened. A second heat-treatment is necessary to cure the bonding monomer, but this has no apparent deleterious effect on the rest of the laminate. Reheating is usually done in an oven.

The properties of the finally cured products depend largely upon the nature of the base material used and cannot be stated generally. With paper and fabrics, however, Columbia Resins give more flexible, less brittle laminates than do either phenol formaldehyde or urea formaldehyde resins. Some of the properties of certain more or less typical laminates are shown in table on the following pages.

The table of properties is a compilation of current data on transparent C.R. 39. Data for cast methacrylate plastics as determined in the Columbia Chemical laboratory are included for comparison since results obtained, even by standard methods, in different laboratories sometimes vary. Most of the values shown for glass were taken from available literature. All data are subject to change with refinements in testing technique and improvements in the product which will result from continued research.

In determining the properties, the Knoop indentor, as described in the National Bureau of Standards Paper R.P-1220, was used for hardness. This instrument is incorporated in the Tukon Tester made by the Wilson Mechanical Instrument Company, New York, N. Y. The Barcol impressor, by which data for hardness and cold flow were found, is a portable instrument in which an indenting point is activated through a graduated spring. The dial readings were noted as soon as the load was applied to the point and again 15 sec.

Properties of C.R. 39 Laminates

	Fabric Base	Glass Cloth Base
Specific gravity	*1.36	*1.73
Percent of resin	*64	*50
Coefficient of thermal expansion, in. per deg. C. x 10^{-5} :		
−38 deg. C. to 50 deg. C.	*4.2	
50 deg. C. to 70 deg. C.	*2.5	
70 deg. C. to 90 deg. C.	*3.0	
90 deg. C. to 110 deg. C.	*2.4	
−31 deg. C. to −18 deg. C.	.....	*2.3
−18 deg. C. to 0 deg. C.	.....	*1.7
0 deg. C. to 25 deg. C.	.....	*1.9
Impact strength, ft. lb. per in., Izod, notched:		
−55 deg. C.	*2.0	23.0 (25 deg. C.)
−50 deg. C.	*3.5	
70 deg. C.	*4.3	
Tensile strength:		
Ultimate, lb. per sq. in.	*7,500	*30,400
Elongation at ultimate, percent	4	.....
Tangent proportional limit, 0.01 percent offset, lb. per sq. in.	*1,800	*3,600
Yield strength, 0.2 percent offset, lb. per sq. in.	.....	12,700
Modulus of elasticity	*550,000	*1,700,000
Weathering, 200 hr.	*no surface defects	*no surface defects
Burning rate	⅛ in. thick— *0.5 in. per min. 1/16 in. thick— *0.7 in. per min.	1/16 in. thick— *0.9 in. per min.

Specimens were as follows:

Type	Resin Content, percent	Size, in.
Canvas	64	0.079 x 14 x 14
Canvas	64	0.110 x 14 x 14
Canvas	64	0.229 x 14 x 14
Canvas	64	0.469 x 14 x 14
Glass Cloth	50	0.065 x 14 x 14
Glass Cloth	50	0.099 x 14 x 14

* Tests made in independent laboratories.

Properties of Monomer

	C.R. 39	Methyl Methacrylate
Boiling point, deg. C.	160 (2 mm.)	100 (760 mm.)
Refractive index, n_D, 20 deg. C.	1.450	1.415
Specific gravity at 25 deg. C.	1.133	0.945

later. The latter reading was recorded as hardness and the difference as cold flow. To determine plastic yield a 1,000-lb. load was applied through two 1-in. dia. flat anvils to a ½-in. cube of the test material. The decrease in cube thickness after 24 hr. was measured with a dial gage.

For the rotary abrasion test, specimens were rotated at 78 r.p.m. under a ⅜-in. felt pad filled with No. 302 emery under a load of 76 grams. Abraded specimens were compared visually and the abrasion values calculated by dividing the number of revolutions used to abrade the specimen by the number of revolutions needed for the equivalent abrasion of methacrylate resin. Abrasion resistance was also determined with a modification of the Gardiner test for the abrasion resistance of point film. Specimens were abraded by letting weighted amounts of No. 60 emery fall on them at an angle of 45 deg. from a funnel through a vertical tube 6 ft. long and 1 in. in diameter. The abraded specimens were compared visually and the abrasion values expressed two ways: (1) By dividing the weight of emery used to abrade the specimen by the weight of the emery needed for the equivalent abrasion of glass and (2) by dividing the weight of the emery used to abrade the specimen by the weight of the emery needed for the equivalent abrasion of methacrylate resin.

The modulus of elasticity was calculated from the deflection observed under one half the breaking load with A.S.T.M. test D651–41T, which was also used for determining the data on deflection at break. To find the break limits a ½-lb. steel ball was dropped from increasing heights until the specimens failed. Data shown are for the greatest drop that specimens withstood. All specimens were ⅛x15x20 in. and the curved specimens were bent to an 18-in. radius along the 15-in. dimension.

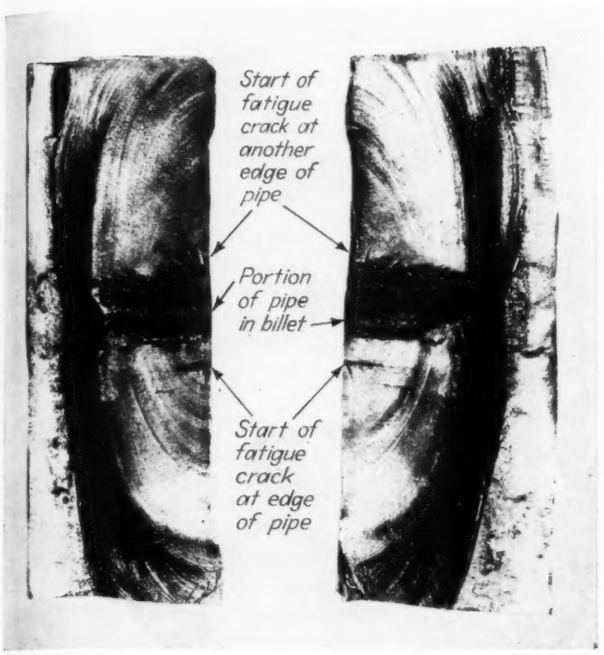
Thermal expansion was determined by measuring the expansion with a dial gage of a specimen about 3 in. long supported vertically by a Pyrex holder in an air bath surrounded with a well-stirred liquid bath. In determining heat distortion of 10 mils the A.S.T.M. test D648–41T was used. This was then carried on with continuous measurement of the deflection until either the specimen softened or a temperature of 130 deg. C. was reached.

White light transmission and haze values before and after aging were measured with a hazemeter of the kind described by Axilrod and Kline in the *Journal of Research* of the National Bureau of Standards, Vol. 19, p. 370 (1937). Blue light transmission was measured with a Cenco-Sheard-Sanford photometer fitted with a dense blue Cenco No. 1 filter. All specimens were ⅛ in. thick. In the light transmission and hazing tests, aging was accomplished by a modification described by Kline, Crouse and Axilrod in *Modern Plastics* for August, 1940, p. 49, in which specimens were exposed for 200 hr. in a horizontal plane 7 in. below an S-1 bulb in a BM6 sun lamp with two 2-hr. periods in a fog chamber each day.

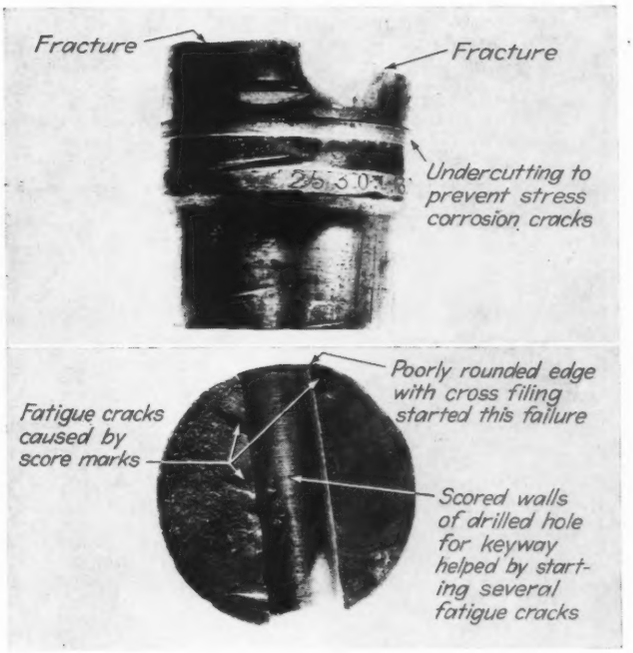
Power factor, dielectric constant and dielectric loss were determined at 1 kc. and 1 mc. using a General Radio power factor bridge. Dielectric strength was found by the methods described in paragraphs F-2V (8) and F-2V (9) of Bureau of Ships Specification 17 P8 (INT) of Apr. 1, 1941.

In connection with electrical properties it should be noted that another formulation known as C.R. 38, now being developed, has power factors at 60 cycles and radio frequencies similar to those of the phenol formaldehyde resins. Its dielectric strength and arc resistance will excel even the urea formaldehyde resins. When laminated, it is more flexible than either the phenolic or urea resins.

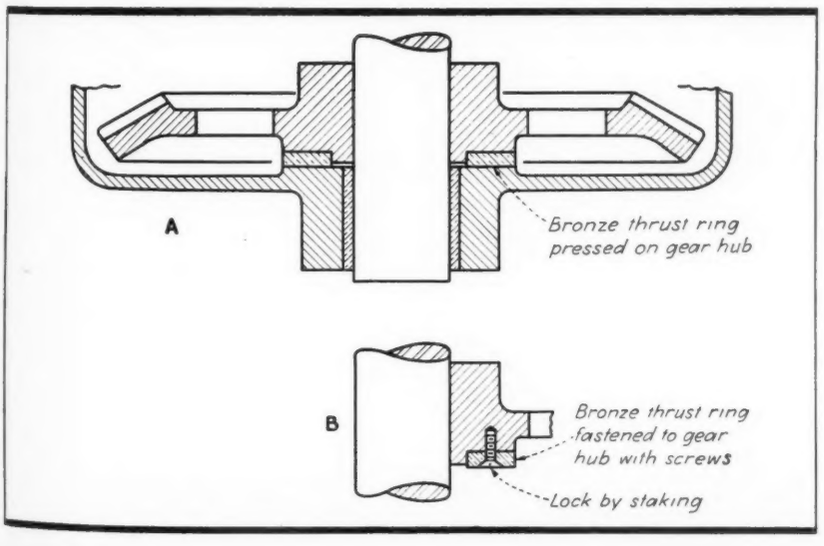
Causes and Cures



Fatigue cracks are sometimes started by pipes in forgings with the result that the forging fails in service. In the illustration is shown a main rod in which a pipe was present. The pipe originated in the ingot and was not cropped off and this was rolled into the billet. In forging the rod the pipe was so closed up that it escaped detection during inspection. In service a fatigue crack started on each side of the pipe and progressed across the section of the end of the rod from inner surface of the eye to the final fracture of the section. The pipe is plainly seen in both fractures with fatigue cracks progressing out from edge of the pipe and surface of the eye. Fatigue cracks start from minute nuclii which tend to concentrate reversing stresses that have to be under the yield point to produce fatigue cracks.


Fracture
Fracture
Undercutting to prevent stress corrosion cracks
Poorly rounded edge with cross filing started this failure
Fatigue cracks caused by score marks
Scored walls of drilled hole for keyway helped by starting several fatigue cracks

Slots in long sections such as the keyways in piston rods and valve stems should have the edges rounded off in a generous way and the surface of such rounds polished, not cross-filed as is frequently done. The illustration shows a piston rod where such lack of finish caused failure of the part. Portion of rod shown is battered as result of the fracture. Fatigue crack is seen to have started from one edge and progressed across most of one side before the final rupture of the section. Some time previous to rupture the opposite section started to crack along the roughly finished walls of the keyway and the rod broke when slightly more than half of its total section was cracked. Keyway was evidently made by drilling several holes and cutting out metal leaving the ends of the keyway rough and scored as drilled.



Effect of heat on press fits must be considered in some applications, depending upon materials used and relative coefficients of expansion. At *A* is shown a bronze thrust ring which was fastened by only a press fit to the hub of a cast iron gear. The heat generated by friction expanded the bronze ring more than the cast iron hub and destroyed the fit, leaving the ring loose so that the unlubricated back face of the ring wore away rapidly and caused excessive heating. Cure was to lock the ring in place as shown at *B* with machine screws.

PRODUCT ENGINEERING will pay a minimum of $3 for each example published in Causes and Cures. Where illustrations are necessary, include drawings, rough sketches or photographs.

Babbitting of Cast Iron Improved by New Process

A saving of tin in babbitts and reduction of machining on cast iron bearing shells have resulted from the use of a new process producing strong bonds between these two materials. Previously anchor holes or grooves and the use of tin babbitts of high tensile strength rather than high lead babbitts were necessary.

THE inability to "tin" cast iron and certain other metals so that they could be soldered, or so that babbitt could be bonded to them, has often been a deciding factor in design and selection of materials and has often necessitated the use of higher grade materials. In bearings particularly this has been true. A recent announcement of a chemical cleaning process that enables "tinning" of cast iron, as well as producing more consistent bonds on steel, in an obscure laboratory in an abandoned garage suggests the familiar better-mousetrap story. Engineers, chemists, and metallurgists of the largest firms in the country have been investigating, making their own tests, and are adopting this new method. The applications and results of using the process that are given here, are reported by a few of these users.

Savings of tin in bearing babbitts as well as the possibility of completely eliminating costly anchoring methods are two of the outstanding results of application of the Kolene process. Adoption of the process by The Cooper-Bessemer Corporation in its two plants has resulted in a savings of 99 percent in the tin content of bearing babbitt. It was found that the process produces an exceptionally firm and uniform bond between lead-base babbitt alloy and Meehanite metal from which bearing shells of large compressors are now cast. Anchor holes and grooves are no longer necessary.

"The bonding is so uniform and firm," according to T. E. Eagan, chief metallurgist, "that we have been able to reduce the bearing thickness to a small fraction of that formerly required." The installation for handling the process at the Mt. Vernon works, which is pictured herewith, is said to be one of the largest built to date. This equipment was not supplied with the process but was designed to suit conditions in this plant.

Extremely simple in its principles and application, the original equipment, which is still in use at the Kolene Corporation laboratory and shop in Detroit, consists of four open-top vats not much larger than ordinary bathtubs, heated by gas burners underneath them. The hood shown in the illustrated installation is a refinement designed to remove fumes and protect careless workers from splashing hot acids and chemicals.

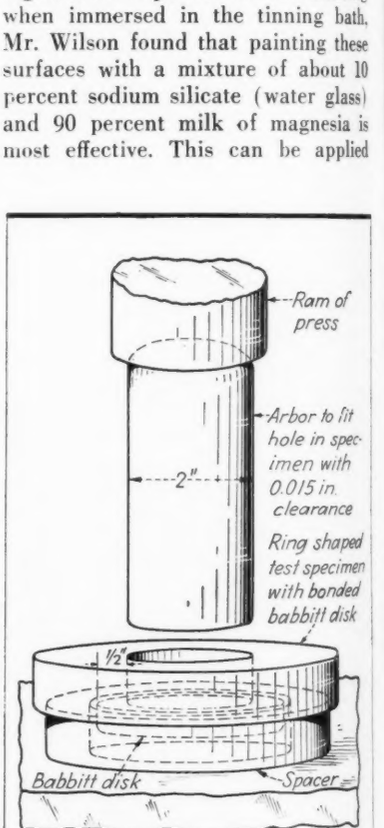
While the significance of the development is now largely in the saving of critical material, it also enables the design of bearings of slightly smaller size because it permits reduction of the thickness of both the babbitt metal and the bearing shell. Neither cored anchor holes or machined anchoring grooves are required.

One of the objects of using high tin babbitts instead of lead base babbitts, which have better frictional characteristics than tin babbitts, is their higher tensile strength. High tensile strength is advantageous when the babbitt must depend upon this property for its retention in anchor holes or grooves in a bearing shell. However, with a strong bond between the babbitt and cast iron the tensile strength of the babbitt becomes relatively unimportant so that lead can be used instead of tin. In order to bond high lead babbitt to a bearing shell heretofore, it has been necessary to use a steel or bronze backing. The Kolene process now makes possible babbitted cast iron or steel bearings that have the uniformity of life and heat dissipating properties of thin wall, steel backed bearings.

The actual strength of the bond produced between a cast iron bearing shell and its liner has been investigated by several firms using various test methods. J. H. Shoemaker, president, Kolene Corporation, claims strengths are several times those afforded by anchor holes alone. A report by Charles D. Wilson, Steam Turbine Department, Allis-Chalmers Manufacturing Company, whose work with the process is yet only in the preliminary stages, shows results on cast iron bearing shells superior to any previously used processes. In these tests the bonding material was Kolene's Flo-Met'l, a special alloy essentially 90 percent lead, the balance being not more than 5 percent tin with an antimonial content that reduces surface tension.

On steel bearing shells the process gave just as good results as the ordinary acid cleaning treatment and gave them much more consistently, Mr. Wilson found.

In order to prevent tin from adhering to certain portions of the bearing when immersed in the tinning bath, Mr. Wilson found that painting these surfaces with a mixture of about 10 percent sodium silicate (water glass) and 90 percent milk of magnesia is most effective. This can be applied



Test set-up for determining stripping pressure to break bond between babbitt and cast iron

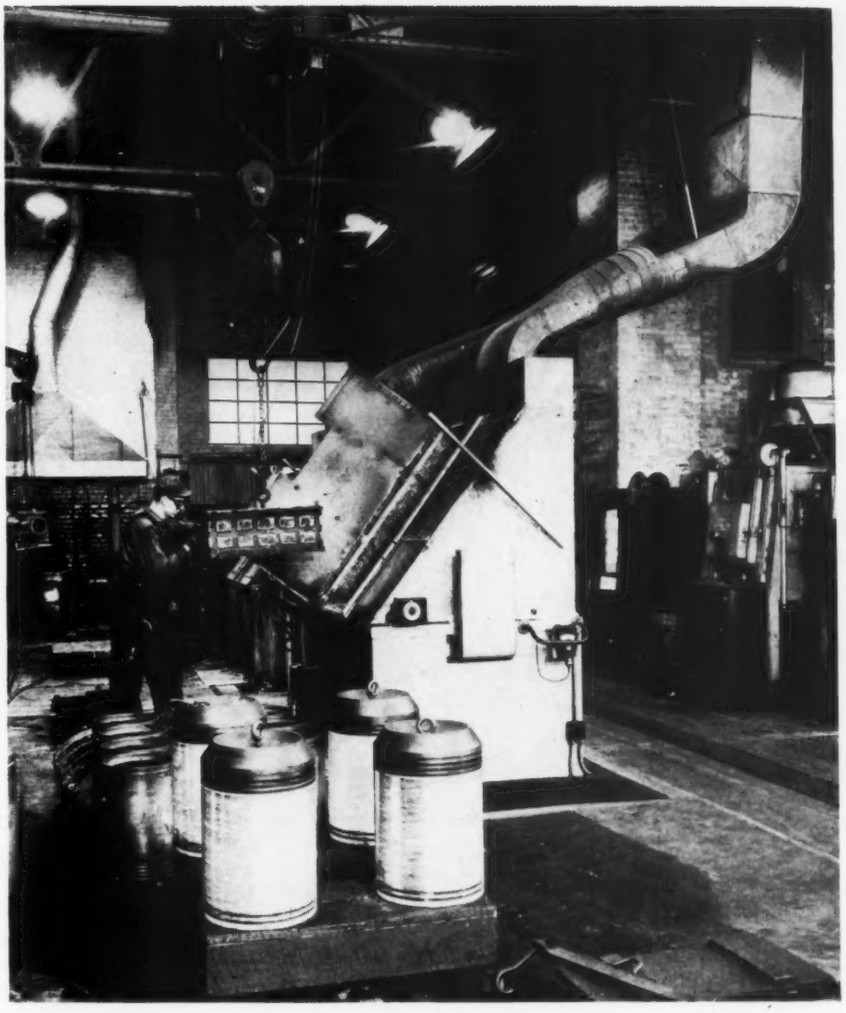
after using the Kolene cleaner and before final acid dip. The main objection to this masking material is that when subjected to the heat of the tin bath, it forms a hard coating which is sometimes troublesome to remove. However, because Flo-Met'l has such a low surface tension and uses so little metal, most manufacturers find it more economical to coat the entire assembly.

In a preliminary report of the Ingersoll-Rand Company, the following conclusions were drawn after tests to determine relative tinning and bonding values resulting from use of the process. In this instance the use of the method is still considered to be in the experimental stage.

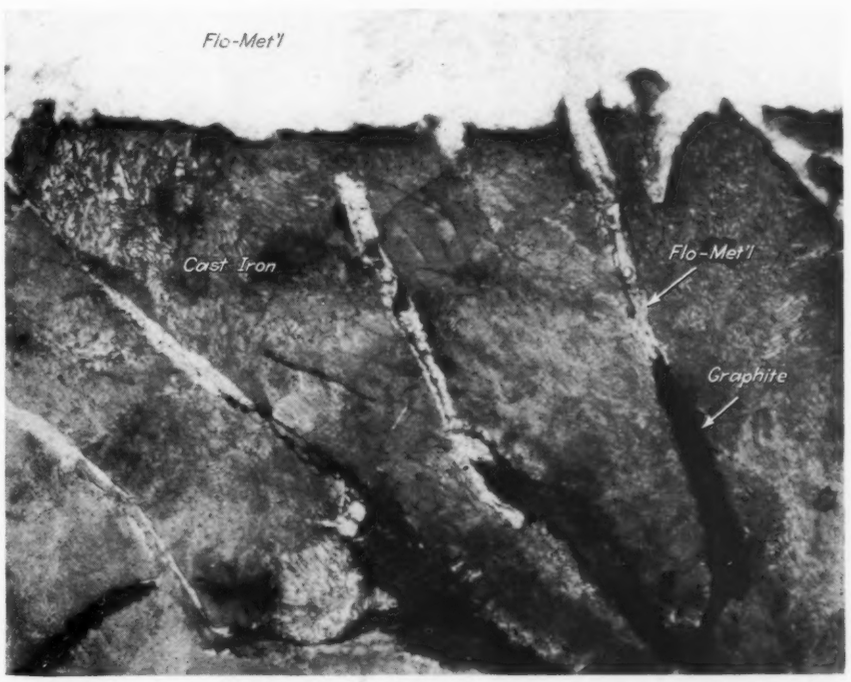
1. The Kolene cleaning and Flo-Met'l coating as a tinning agent for steel is the equal of high tin solders.
2. Cast iron cleaned by the process and coated with Flo-Met'l produced a bond practically the equal of tinning on steel.
3. Tin solder on Flo-Met'l produces a slightly better bond than Flo-Met'l alone.
4. Of the two high lead babbitts tested, both bonded equally well. In all tests the babbitt metal fractured before the bond let go.
5. High tin solder and high tin babbitt on steel plate gave the highest values in the stripping tests. On cast iron plates high tin babbitt showed a slight advantage over high lead babbitts.
6. The stripping values of babbitts are influenced by the tensile strength of the tinning material.
7. Flo-Met'l coated parts can lie around for at least a couple of weeks without affecting their ability to bond to other parts.

Tests of tinning value were made for Flo-Met'l on steel and cast iron, tinning on steel, and Flo-Met'l preparation and tin plate on cast iron. Bonding tests were made on two high lead babbitts and one high tin babbitt under each of the four tinning conditions just named. In metallographic examinations of three babbitt bonding test samples, a good bond was found at all points examined.

Use of the process to prepare metal surfaces for protective coatings of lead or other metals is also being investigated. In one instance the process made possible the application of a protective coating inside and outside a steel tube that was hydrogen brazed to a cast iron fitting. This avoided the necessity for special electrodes to produce the coating by electroplating. It was necessary to clean the steel tube of scale, rust, the brazing flux, and



New metal-cleaning installation designed by Cooper-Bessemer for the Kolene process of bonding high lead babbitts to Meehanite bearing shells



Babbitt on cast iron, magnified 750 times. White lines are graphite cavities in iron filled with Flo-Met'l

scale from the weld. If this assembly were pickled sufficiently long to remove the scale and flux, graphite in the cast iron would be exposed and thereby would make it impossible to apply a coating by any known commercial method. By the Kolene cleaning method of converting the impurities to an easily soluble oxide and then, without exposing any additional graphite, removing this oxide, it was possible to coat the assembly inside and out by dipping.

Rebabbitted bearings are often bored out to produce a bright surface for tinning, thus enlarging of the shell bore and increasing the babbitt lining thickness. Using the Kolene process it is not necessary to have bright surfaces. Hence the babbitt is removed by solvents and the surface to be tinned is cleaned without reboring. The babbitt lining is, therefore, held to the original thickness.

Another use of the Kolene process is in tinning Alnico magnet metal, which has never been bonded to other parts except by casting. The tinning of Alnico makes it possible to solder other metals to it.

Kolene coated chaplets have been found to produce desirable advantages in foundry production of iron castings.

The Kolene Process

Essentially the process, as applied to cast iron, consists of dipping the part to be coated into four baths for short time intervals. The first is a solution of molten oxidizing salts at about 800 deg. F., which oxidize the surface of the part. The second bath is a mixture of water soluble reducing salts at about 270 deg. F. The part is rinsed in water before and after dipping in this bath. This is followed by a quick dip in dilute hydrochloric acid, fluxing, and finally a dip in the tinning bath.

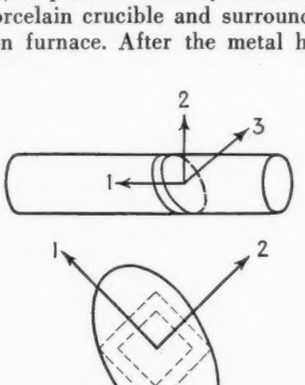
Tinning alloy preferred is a composition containing 90 percent lead, not more than 5 percent tin, and enough antimony to give low surface tension or wetting capacity. The wetting capacity is believed to be highly important in giving the coating a penetrating power. Other features of this coating are said to be its uniform thickness, corrosion resistance, its equal effectiveness on steel or cast iron, and elimination of hydrogen inclusions as in tinning.

In addition to the surface cleaning that is accomplished by the process, the oxidation of exposed graphite in the cast iron surfaces, without exposing additional graphite, is considered highly important. Photomicrographs of coated cast iron parts show that pockets left by oxidized graphite appear to be filled by the lead alloy, and thus indicate how close the union is between the metals. In the accompanying reproduction, which is magnified 750 times, the light colored area is the babbitt and the darker area is the iron. The dark lines in the iron are graphite and the light lines are where Flo-Met'l has penetrated cavities formerly occupied by graphite. The black graphite ends at about 0.002 in. from the surface. Chisel tests also showed the tightness of bond on this specimen.

SEEKS BETTER TRANSFORMER CORES

SEEKING a still better magnetic material for transformer cores than Hipersil, Dr. Sidney Siegel, a physicist at Westinghouse Research Laboratories, is testing the magnetic characteristics of small hollow square sections cut from large crystals of various alloys in such a way that their sides are parallel to two principal crystal axes, which are directions of easy magnetization.

In the preparation of these one-inch square transformer cores a rod of the alloy, such as 96 percent iron and 4 percent aluminum, is placed vertically in an 8-in. deep test-tube-shaped porcelain crucible and surrounded by a cylindrical induction furnace. After the metal has melted, the heating unit is raised out of the furnace at 1 in. per hr. The cooling process, which takes all day, leaves the rod a single crystal.



Slices are cut from the rod at such an angle that two of the axes of the crystal at right angles to each other are in the plane of the slice. The 1-in. square transformer cores are then cut from the slice in such a way that their sides are parallel to the two crystal axes.

Design of Self-Cooled Journal Bearings — I

MERHYLE F. SPOTTS
Northwestern Technological Institute

First article in a series that presents a method and procedure for designing self-cooled journal bearings. Part I deals with viscosity-temperature relations, film pressure, and friction. In Part II there will be developed equations for determining rate of heat produced and for calculating area of housing, and will conclude with several examples to illustrate design procedure.

FRICTIONAL RESISTANCE of a journal bearing produces heat, consequently temperatures of the oil and of the surrounding parts are raised. This change of temperature reduces the viscosity of the lubricating oil, and thus affects all the factors which enter into the design of a bearing. Engineers usually attempt a design by assuming some value for the operating temperature of the oil film, but this method in general leaves much to be desired.

Since it is impossible to foretell all the conditions which may be present in service, bearing design, like all other engineering design, is no more accurate than the assumptions which the engineer necessarily had to make at the beginning. Theoretical studies of bearing performance nevertheless are useful. By assigning values to one of the variable factors the designer can plot curves showing the effect on other quantities involved and thus be greatly aided in choosing the best over-all proportions of the different parts of the bearing.

VISCOSITY AND NEWTON'S LAW. A layer of lubricating oil will prevent the heavy friction of metal-to-metal contact of moving parts, but the friction of the oil itself is introduced into the problem. Thus, as is indicated in Fig. 1, a force of F lb. is necessary to move the plate which is in contact with the film of thickness h in. When the plate moves it does not slide along on top of the film. Oil adheres to the plate and motion is accompanied by slip or shear between the oil particles throughout thickness h. If the plate and the oil adhering thereto move with velocity U in. per sec., the velocity of the oil at intermediate points in its thickness varies directly with the distance from the fixed or bottom plate. As stated by Newton where μ is the viscosity in lb. sec. per sq.in., and A is the area of the plate in sq.in., then the shearing stress s_s in lb. per sq.in. in the oil film is

$$s_s = \frac{F}{A} = \mu\left(\frac{U}{h}\right) \qquad (1)$$

This equation assumes that the area A is very large as compared to h, and that disturbances around the edges of the plate may be neglected.

Viscosity is thus the measure of the ability of an oil to resist shearing stress. It is a molecular property, and the work done by the force F is turned into heat.

From Equation (1) it may be determined that the dimensions of viscosity are lb. sec. per sq.in. That is if a force F equal to 1 lb. is required to move a plate having an area A equal to 1 sq.in. at a height h equal to 1 in. with a velocity U equal to 1 in. per sec., the viscosity of the oil would be 1 lb. sec. per sq. in. Oils used for lubricating purposes have viscosities very much less than unity.

Commercially in specifying the viscosity of lubricating oils the absolute units of lb. sec. per sq.in. are usually not used. One method in wide use is to specify viscosity by "Saybolt universal seconds" at some given temperature, the Saybolt viscosity being the number of seconds required for 60 c.c. of oil to flow through a standard vertical tube. Conversion from S.U.V. units to absolute units can be made with sufficient accuracy by the following equation, where in μ is the viscosity in lb. sec. per sq.in. at temperature t deg. F., γ_t is the specific gravity of the oil at temperature t deg. F., and S is the viscosity in Saybolt universal seconds at the same temperature:

$$\mu = 0.145 \times 10^{-6}\,\gamma_t\left(0.22S - \frac{180}{S}\right) \qquad (2)$$

The specific gravity of oil changes with temperature, becoming less as the temperature rises. Where γ_{60} is the specific gravity at 60 deg. F., and t is the temperature in deg. F., the specific gravity γ_t at any temperature can be determined by

$$\gamma_t = \gamma_{60} - 0.000365\,(t - 60) \qquad (3)$$

Variation of Viscosity With Temperature

Saybolt viscosity determinations for lubricating oils are usually made at the two temperatures, 100 deg. F. and 210 deg. F. It is necessary in bearing design for the engineer to determine the viscosity at any desired temperature. A convenient way to do this is to use the charts prepared by the American Society for Testing Materials. The coordinates on this chart

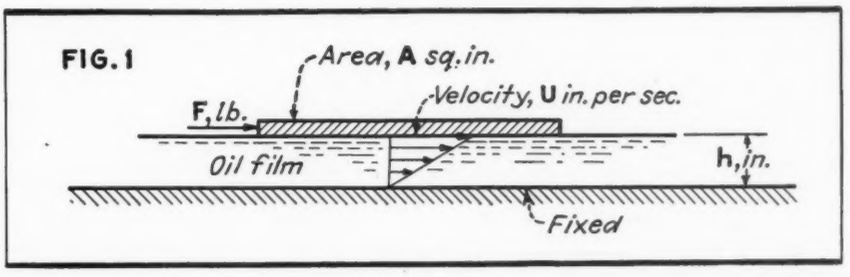


Fig. 1—Diagram showing how velocities of points in oil film moved by a flat plate vary in accordance with Newton's Law

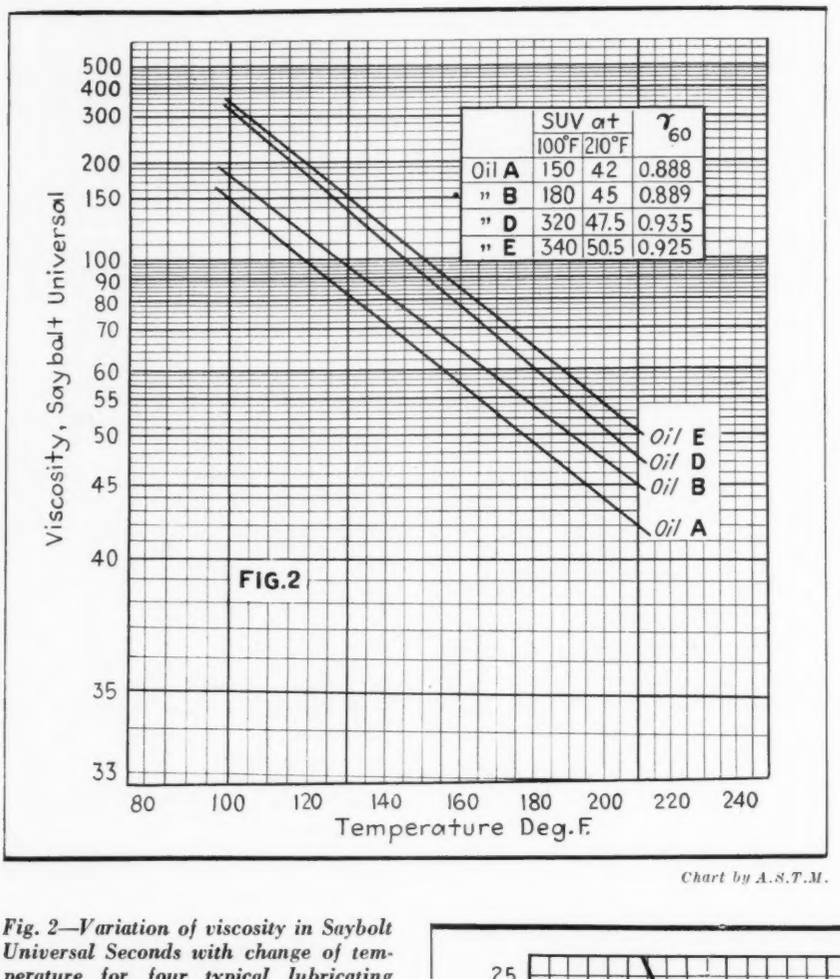


Chart by A.S.T.M.

Fig. 2—Variation of viscosity in Saybolt Universal Seconds with change of temperature for four typical lubricating oils. Fig. 3—Variation of viscosity in absolute units with change of temperature for the oils plotted in Fig. 2

are temperature in deg. F. and viscosity in Saybolt universal seconds. The chart is arranged so that if the viscosities at two different temperatures are located on the chart, a straight line between the two points will give the viscosity at all other temperatures. Fig. 2 is a reproduction of a portion of one of these charts on which the viscosities of four typical bearing oils, A, B, D, and E have been plotted. Since the designer requires the viscosity in absolute units, the viscosities of the four oils A, B, D, and E are shown in lb. sec. per sq.in. units in Fig. 3. These curves are easily drawn by reading the S.U.V. values from Fig. 2, and then by the use of Equations (2) and (3) transforming them to lb. sec. per sq.in. units.

Petroff's Bearing Equation

Newton's Equation (1) can be easily adapted to a journal bearing problem providing the velocity of the journal surface is high, the viscosity of the lubricant is high, and the load is so light that the journal remains substantially in a central position in the bearing. In Fig. 4 the flat plate of Fig. 1 is assumed to be wrapped into a cylindrical shaft. If r is the radius of the journal, and L in. its length in the axial direction, then area of wetted surface in sq.in. is

$$A = 2\pi rL$$

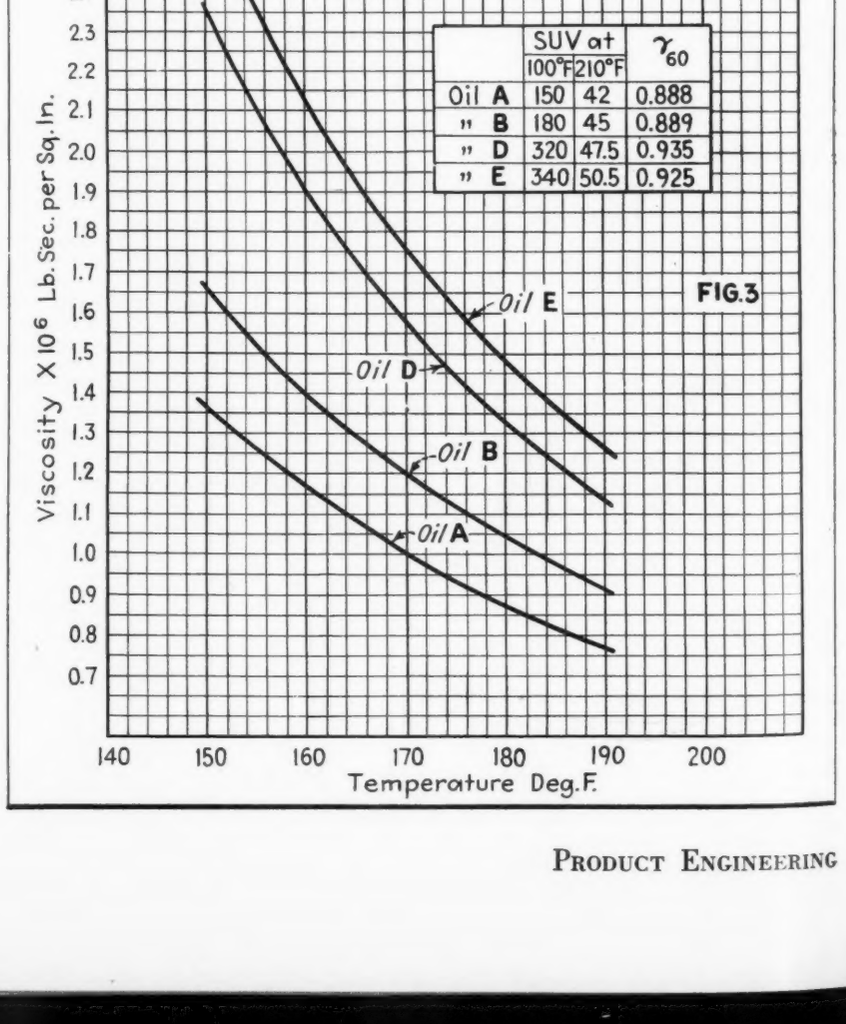
The thickness h of oil film becomes the radial clearance c, or the difference between the radius of the bearing and the radius of the journal. Equation (1) can then be written

$$F = 2\pi\mu UrL/c$$

If F_1 is taken as the tangential frictional force per in. of axial length, then F equals F_1L, and the equation becomes

$$\frac{F_1}{\mu U}\left(\frac{c}{r}\right) = 2\pi \qquad (4)$$

This is known as Petroff's equation. Theoretically it applies only when bearings like that shown in Fig. 4 carry zero load. Note that the quantity expressed by the left side of the equation is non-dimensional.



Generation of Pressure Within the Film

The flat plate of Fig. 1 when parallel to the surface of the fixed plate and moved over the oil film is incapable of supporting a vertical load. But if the moving plate is tipped at a small angle as shown in Fig. 5, and then moved it is found that a considerable weight can be supported thereon, since the oil is drawn beneath the inclined plate and large hydrostatic pressures are built up because of the wedging action between the oil and the plates.

In a journal bearing such as shown in Fig. 4 when there is a vertical load a similar phenomenon takes place. The shaft is found to shift slightly sidewise in the bearing, and the clearance space is no longer uniform around the shaft. This causes large pressures, which support the load, to be generated in the oil film in the lower part of the bearing. The shaft automatically shifts the amount necessary to keep all forces in equilibrium.

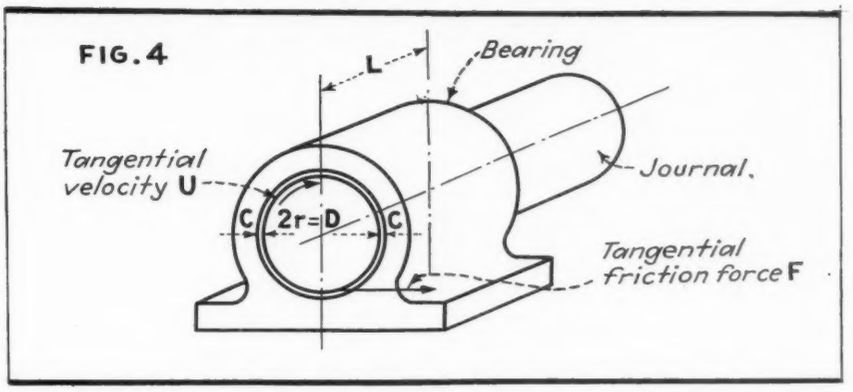


Fig. 4—Diagram to illustrate the similarity between Newton's Law and Petroff's bearing equation

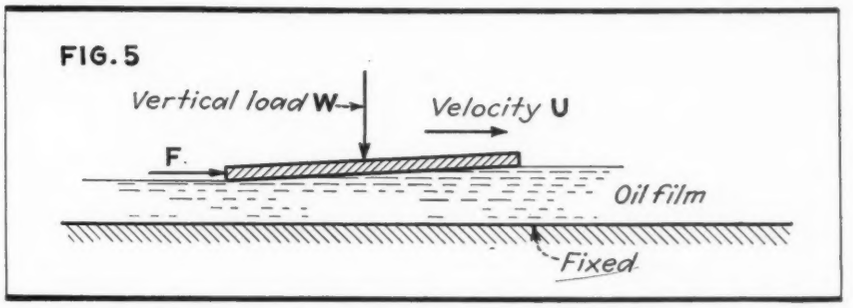


Fig. 5—Moving plate when tipped at small angle supports vertical load because wedging action of oil between plates creates hydrostatic pressure

Load and Friction of Journal Bearing

The mathematical solution for load capacity and friction characteristics of bearings like that shown in Fig. 4 when carrying a vertical load is very complicated. (See Chapter III, Hersey, "Theory of Lubrication.") A solution has been successfully carried through for a bearing which is infinitely long in the axial direction, that is, a bearing wherein loss of pressure in the film at the ends of the bearing is eliminated.

If the ratio of the shift of the center of the shaft to the radial clearance be designated by λ, then in the solution for this bearing the non-dimensional group $(F_1/\mu U)\ (c/r)$ is expressed as a function of λ. That is

$$\frac{F_1}{\mu U}\left(\frac{c}{r}\right) = f_1(\lambda) \qquad (5)$$

The expression for load capacity also results in an equation utilizing a convenient non-dimensional group and λ. That is

$$\frac{W_1}{\mu U}\left(\frac{c}{r}\right)^2 = f_2(\lambda) \qquad (6)$$

in which W_1 is the load on the bearing per in. of axial length.

Equations (5) and (6) apply only to infinitely long bearings of perfectly smooth cylindrical surfaces. In practice, for most bearings the axial length is not great as compared to the diameter. In fact the L/D ratio may lie somewhere between 1 and 2. Thus the loss of oil pressure at the ends is sufficient to invalidate the theoretical results obtained when L/D is taken as infinity.

In addition, the surface of the bearing is usually not a continuous cylinder but is broken by oil holes and grooves, and also chamfers between bottom-half and cap. Thus the conditions which were assumed for the derivation of Equations (5) and (6) are not realized in practice. One is thus forced to turn to experimental results in order to obtain the information necessary to effect a design.

120 Degree Central Partial Bearing

In certain types of machinery the 120 deg. central partial bearing, illustrated in Fig. 6, is widely used. Even though the bottom lining of a bearing embraces more than 120 deg., oil grooves or chamfers may reduce the area effective for carrying load to this amount.

The bearing shown in Fig. 6 has no cap. A close fitting cap adds nothing to the load carrying capacity of a bearing, and usually imposes an unnecessary frictional drag. Often the clearance between shaft and cap is increased to the extent that the friction is reduced to a small amount.

Load and friction characteristics for the bearing shown in Fig. 6 for different L/D ratios are given by the curves in the Reference Book Sheets, pages 253 and 254. These curves were constructed from the results of experimental work done by S. J. Needs as reported in "Effects of Side Leakage in 120 Deg. Centrally Supported Journal Bearings." *Trans.* A.S.M.E. Vol. 56, 1934, p. 721. *Disc.* Vol. 57, 1935, p. 135. It is assumed that the bearing is provided with a copious supply of oil at all times.

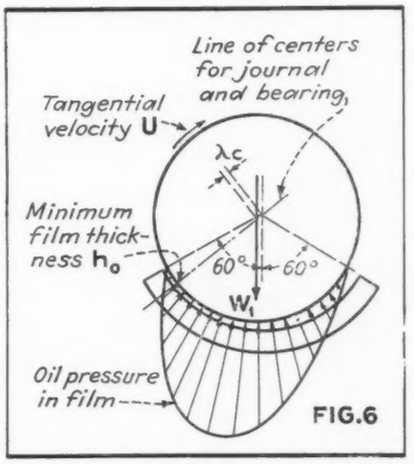
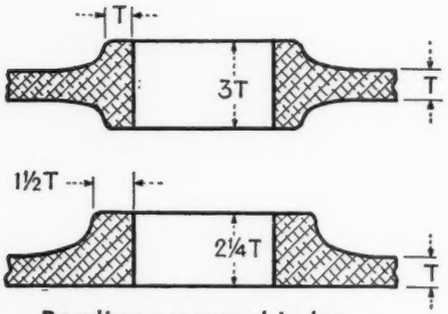


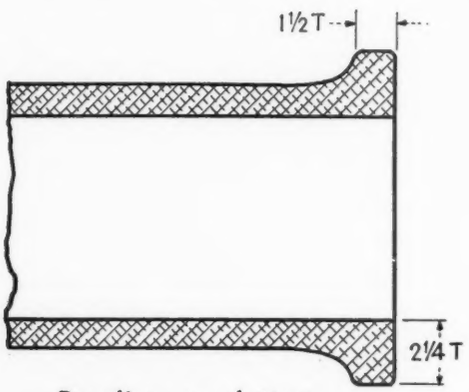
Fig. 6—Diagram showing shift of shaft from the center of bearing, distribution of pressure in oil film, and variation in thickness of oil film

RECOMMENDED DIMENSIONS FO

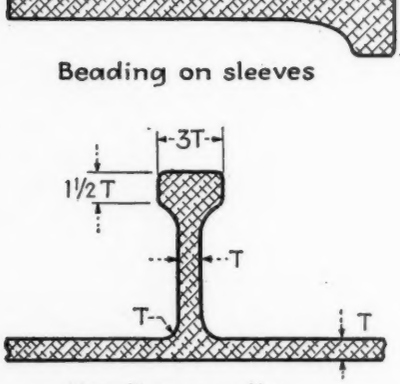
PREFERRED DESIGNS for aluminum castings and forgings showing forms that have proved satisfactory in avoiding unexpected failures and difficulties in production. Included here are approved methods for joining walls of the same and different thicknesses, dimensions for beading around holes, sleeves and ribs, flange and bolt hole proportions, and other design proportions.



Beading on cored holes
(double bead preferred)

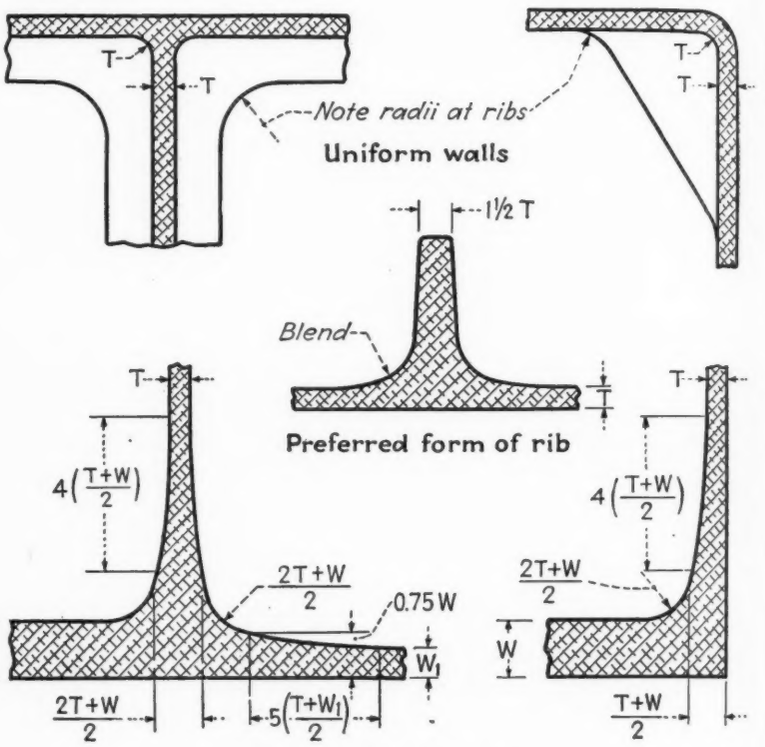


Beading on sleeves

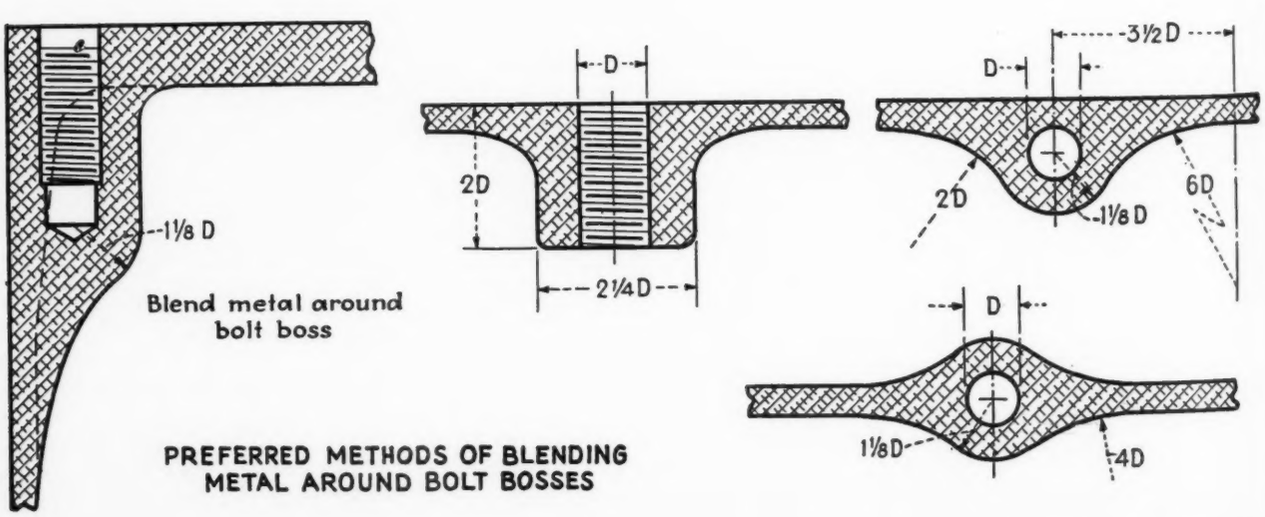


Beading on ribs

DIMENSIONS FOR BEADING ON CORED HOLES, SLEEVES, AND RIBS

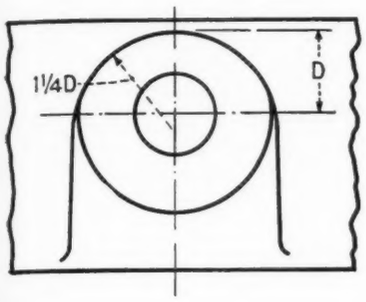


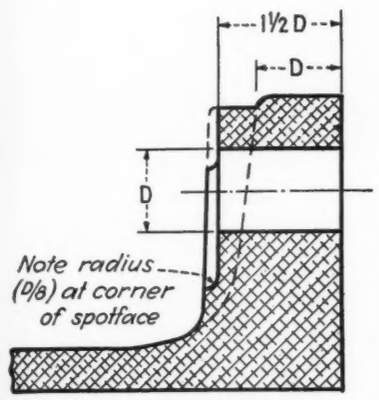
METHOD OF JOINING ALUMINUM WALLS AND RIBS



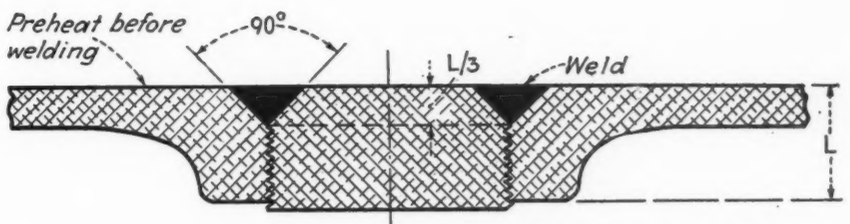
PREFERRED METHODS OF BLENDING METAL AROUND BOLT BOSSES

FOR ALUMINUM CASTINGS

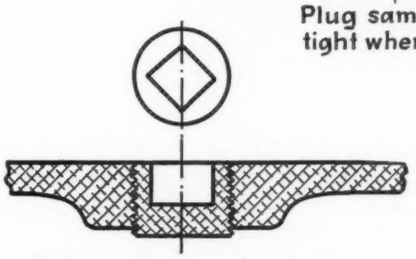




RECOMMENDED FLANGE AND BOLT HOLE PROPORTIONS

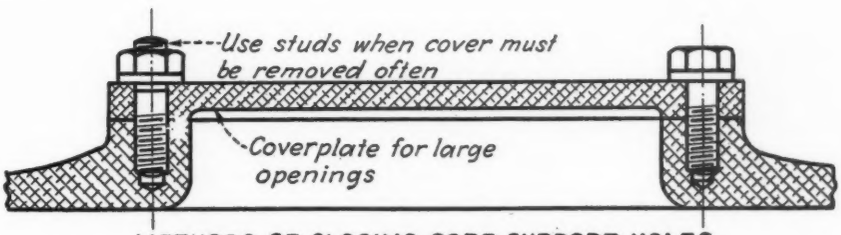


Plug same material as casting. Must be tight when entering. Gage with Am. Std. pipe tap

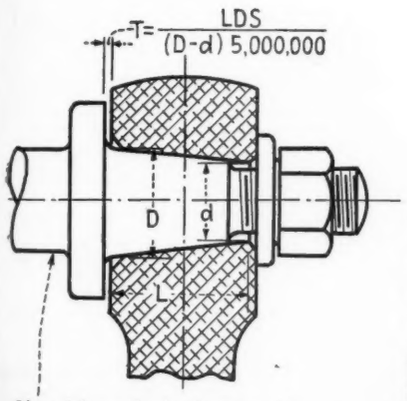


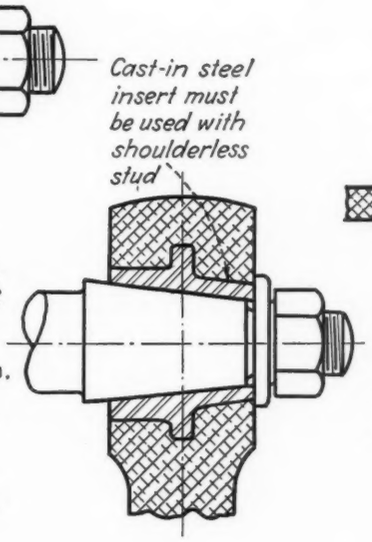
Hollow square aluminum pipe plug

Welsh plug, 17 ST alloy counterbore 0.001 to 0.005 in. larger than plug



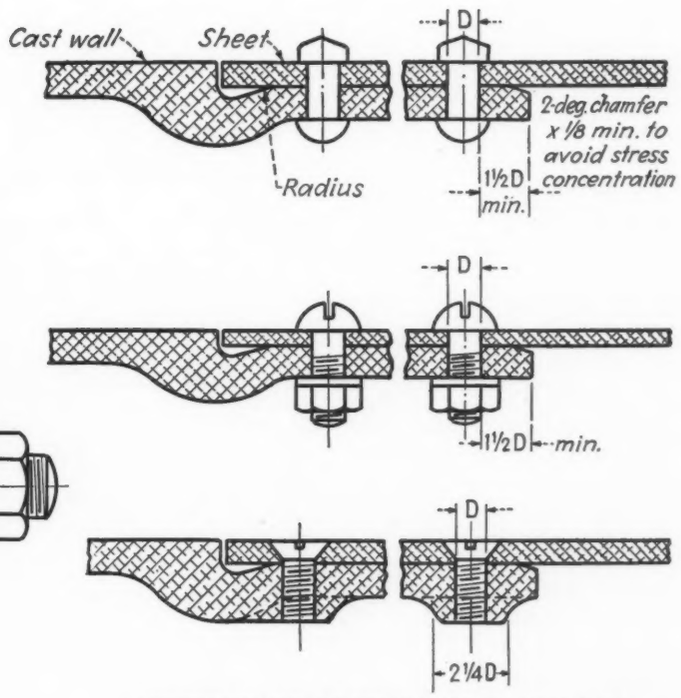
METHODS OF CLOSING CORE SUPPORT HOLES





When exact yield strength, S, is unknown, assume
S=30,000 lb. per sq. in. for forgings
20,000 lb. per sq. in. for heat-treated castings
10,000 lb. per sq. in. for as-cast and annealed castings

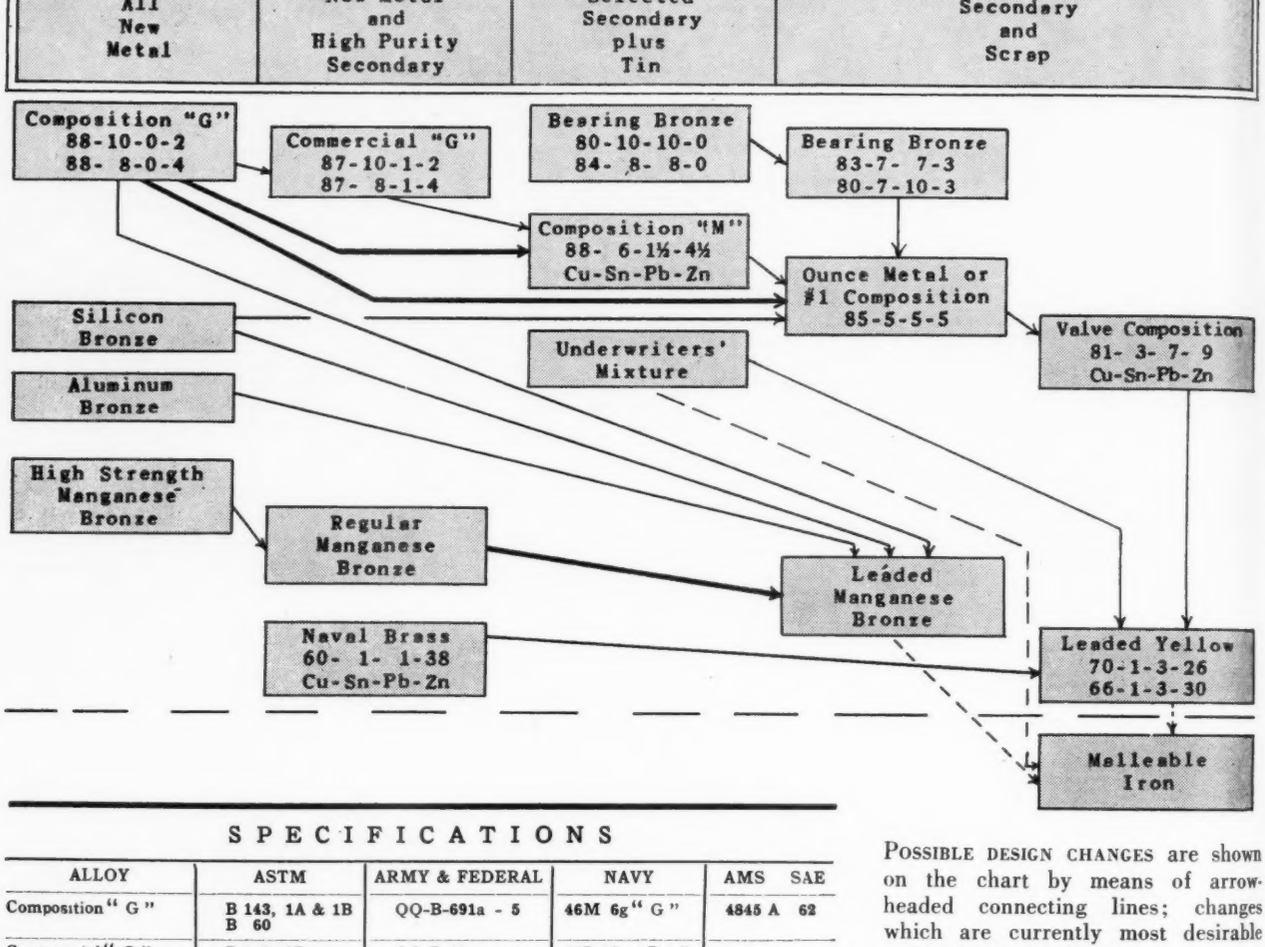
METHODS OF LOCKING TAPER STUDS



METHODS OF ASSEMBLING ALUMINUM SHEET FLUSH WITH SURFACE OF ALUMINUM CASTING

Chart for Downgrading Bronze

To guide engineers and designers in specifying lower grades of critical material for brass and bronze castings, the accompanying chart has been prepared and issued by the Specifications Branch of the WPB Conservation Division.


All New Metal
New Metal and High Purity Secondary
Selected Secondary plus Tin
Secondary and Scrap
Composition "G" 88-10-0-2 88- 8-0-4
Commercial "G" 87-10-1-2 87- 8-1-4
Bearing Bronze 80-10-10-0 84- 8- 8-0
Bearing Bronze 83-7- 7-3 80-7-10-3
Composition "M" 88- 6-1½-4½ Cu-Sn-Pb-Zn
Ounce Metal or #1 Composition 85-5-5-5
Valve Composition 81- 3- 7- 9 Cu-Sn-Pb-Zn
Silicon Bronze
Underwriters' Mixture
Aluminum Bronze
High Strength Manganese Bronze
Regular Manganese Bronze
Leaded Manganese Bronze
Naval Brass 60- 1- 1-38 Cu-Sn-Pb-Zn
Leaded Yellow 70-1-3-26 66-1-3-30
Malleable Iron

SPECIFICATIONS

ALLOY	ASTM	ARMY & FEDERAL	NAVY	AMS	SAE
Composition " G "	B 143, 1A & 1B B 60	QQ-B-691a - 5	46M 6g " G "	4845 A	62
Commercial " G "	B 143, 2B E-B 143, 2X	QQ-B-691a - 6	46B 5h " P-c "		
Composition " M "	B 143, 2A B 61	QQ-B-691a - 1	46B 8g " M "		
85 - 5 - 5 - 5	B 145, 4A B 62	QQ-B-691a - 2	46B23c " Oz- c "		40
81 - 3 - 7 - 9	B 145, 5A	QQ-B-691a - 11	46B24d		
80 - 10 - 10	B 144, 3A			4842	64
84 - 8 - 8	E-B 144, 3Y	QQ-B-691a - 8	46B22d " II "		
83 - 7 - 7 - 3	B 144, 3B	E-QQ-B-691a - 8			660
80 - 7 - 10 - 3	E-B 144, 3X				
Naval Brass	B 146, 6C	QQ-B-621 - A	46B10f " N-c "		
70 - 1 - 3 - 26	B 146, 6A E-B 146, 6X & 6Y	E-QQ-B-621 X & Y			
66 - 1 - 3 - 30	B 146, 6B	QQ-B-621 - B	46B11f		41
Silicon Bronze		QQ-C-593	46B28		
Aluminum Bronze	B 148, 9A & 9B	QQ-B-671a	46B18c		68
Underwriters' Mixture		WW-C-621a	34F 3c		
H. S. Manganese	B 147, 8B	QQ-B-726b B & C	46B29 " MA-c "	4862	
Regular Manganese	B 147, 8A	QQ-B-726b - A	49B 3e " Mn-c "	4860	43
Leaded Manganese	B 147, 7A	E-QQ-B-726b - A			

NOTE: Specifications, as shown, are approximately equivalent but may not in all cases be interchangeable for procurement and inspection.

POSSIBLE DESIGN CHANGES are shown on the chart by means of arrow-headed connecting lines; changes which are currently most desirable are indicated by the heavier connecting lines. By examining the end use, designers should during the emergency specify the least restrictive material for the service required.

The chart shows most of the important specifications grouped in columns according to the material required by an ingot maker or foundryman. Four classifications are given. "All New Metal" includes No. 1 and No. 2 copper as well as electrolytic. "High Purity Secondary" is exemplified by such items as fired cartridge cases currently used to make regular manganese bronze. In any specification where the lead is equal to or greater than the tin, the tin content of bronzes can generally be introduced from secondary sources. Lead is generally the contamination in secondary supply that restricts use of tighter specifications.

Articles economically produced as alum'num die-castings

Factors to Be Considered When Designing Die-Castings—I

HERBERT CHASE

In this article, the first of a series of three, is given a comparison of the composition and properties of alloys for die-castings. Part II will contain rules for designing parts requiring cores, and the third article will cover threads, gears, inserts, and parts requiring combination dies, and how they may be used economically.

WHEN deciding upon the production method to be used, the die casting process is often given insufficient consideration, especially when only a small quantity of pieces is to be made, because it is assumed that the cost of the dies will be prohibitive. However, dies for castings frequently cost less than the dies that would be required for making the part as a stamping, forging or plastic molding.

Comparing die-casting versus sand castings, the cost of machining the latter is often far greater than the total cost of the die-castings and dies required. This may be true even when only relatively few pieces are to be made, such as a thousand. In some instances, the cost of machining only a few hundred sand castings, plus the cost of the castings, will be greater than the total cost of the same part made as a die-casting, tools included. Some die-castings require no finishing operations other than flash removal. Whatever machining might be required can be done with light cuts and quickly as there is no scale on the surfaces.

Even though the quantity of castings required immediately may not yield a saving in machining sufficient to offset die cost completely, the likelihood of additional orders for the part must also be considered. After the die cost has been amortized, every additional die-casting made adds to the over-all saving realized. If, on the other hand, a sand-casting is chosen, every one produced may require machining, the unit cost of which may not be decreased materially no matter how many are purchased.

Among other advantages of die-

Table I—Approximate Dimensional Limits for Die-Castings in Various Alloys

	Zinc Alloy	Aluminum Alloy and Magnesium Alloy	Copper Alloy (Brass)
Minimum wall thickness, large castings, in.	1/16	0.085	1/8
Minimum wall thickness, small castings, in.	0.030	0.040	0.050
Variations from drawing dimensions per in. of length of dia. min. in., depending upon conditions. As close for Al and Mg as for Zn alloys in certain instances	0.001	0.002	0.003
Cast threads, external, max. number per in.	24	20	10
Cast threads, internal, max. number per in.	24	none	none
Cored holes, min. dia. in.	0.030	3/32	3/16
Draft per in. of length or dia. of cores, in. min.	0.003	0.015	0.020
Draft per in. of length or dia. at side walls, in. min.	0.005	0.010	0.020

castings over sand castings are the following: Die-castings can be made with much thinner sections or walls; sand-castings must be ground to obtain a surface suitable for plating or smooth enameling; die-castings usually require no grinding or buffing to obtain a finish of the required smoothness although sometimes buffing is required before plating. This is an important consideration, for it is not at all unusual for finishing to cost more than the casting, especially if the casting is a rough one.

On the other hand, die-castings can rarely compete in strength with a wrought part of steel, are of a material softer than many ferrous alloys, and in the as-cast condition, usually cost more per pound. Die-castings may have, in common with most castings, some porous sections, and some types of die-casting metals are subject to creep.

Alloys for Die-Casting Compared

There are a score or more non-ferrous alloys suitable for die-casting but the number in extensive use does not exceed ten. Zinc alloys account for about 75 percent of the total die-casting tonnage produced in normal times. By far the largest part of the remainder is in aluminum alloys. Many die-casters, including some of the largest, cast only zinc alloys and only a relatively small number of companies cast any except zinc and aluminum alloys. Still fewer cast the copper base or magnesium base alloys. Though magnesium alloys have been gaining considerably where minimum weight is essential, the total output is only a small fraction of that in aluminum alloys which are employed when light weight is desired but is not so essential.

Table I lists types of die-casting materials under various headings, but does not list tin-base or lead die-castings as they have only slight commercial importance. They cast readily but are low in strength and rank higher in cost than zinc and aluminum. Hence they are employed only in a few special cases, chiefly where certain types of corrosion resistance or high density are considered very essential.

Zinc die-castings have attained widest use because they cast easily at moderate temperatures, are usually lowest in cost per casting, and have mechanical properties superior in most respects to all other die-casting alloys except those based on copper. Remarkably smooth finishes are secured, often so smooth that only buffing is needed preparatory to plating. The moderate casting temperature is conducive to long die life and hence low die costs. Adaptability of zinc to rapid casting in plunger type machines is also an asset.

Aluminum and magnesium are used primarily for parts wherein light weight is a primary asset. Their high strength and hardness are important reasons for copper base alloys being used.

Table II gives the properties of zinc alloys. Their moderate melting point is an advantage but also precludes their use for parts that will be subjected to temperatures of about 300 deg. F. or higher.

There are standard specifications for three zinc alloys, and of these only two, Zamak-3 and Zamak-5, are now in extensive use. All three contain 4 percent aluminum and 0.03 percent magnesium. The addition of aluminum prevents the zinc from attacking (dissolving) iron and steel, and avoids the sticking of plungers in plunger type machines. It also improves casting and physical properties. The use of a small percentage of magnesium is specified in the zinc alloys because of the beneficial effect it has in making the castings dimensionally stable.

In all zinc alloys, iron content should be kept below 0.10 percent, and other impurities below the maximum figures given in Table III. If the lead, tin or cadmium content exceed the limits given, castings become subject to considerable dimensional changes and to intergranular corrosion if exposed to warm, moist temperatures. For this reason, die-casters take precautions to keep impurities within the limits named. Purchasers should see that specifications are rigidly followed, even though this

Table II—Composition and Properties of Magnesium Alloys for Die-Casting

Data on Properties Furnished by Dow Chemical Company, and American Magnesium Corporation

Designation		
ASTM	No. 12	No. 13
SAE	—	501
Dow Chemical Co.	Dowmetal K	Dowmetal R
American Magnesium Corp.	AM 230	AM 263
Composition percent, as in ASTM Specifications		
Aluminum	9.0 to 11.0	8.3 to 9.7
Manganese min.	0.10	0.13
Zinc	0.3 max.	0.4 to 1.0
Silicon max.	1.0	0.5
Copper max.	0.05	0.05
Nickel max.	0.03	0.03
Magnesium	Remainder	Remainder
Properties and Constants		
Tensile strength, lb. per sq. in.	30,000	33,000
Yield strength, lb. per sq. in.	22,000	21,000
Elongation, percent in 2 in.	1	3
Brinell hardness no.	62	60
Izod impact strength, ft. lb.	1	2
Specific gravity	1.81	1.81
Weight per cu. in.	0.066	0.066
Melting point, deg. F.	1100	1120

Table III—Composition and Properties of Zinc Alloys for Die-Casting

Properties and constants are as determined by the New Jersey Zinc Company

Designation		XXI 921 Zamak 2	XXIII 903 Zamak 3	XXV 925 Zamak 5
Composition percent by weight, as provided in ASTM and SAE specifications	ASTM			
	SAE			
	The New Jersey Zinc Company			
	Copper	2.5 to 3.5	0.10 max.	0.75 to 1.25
	Aluminum	3.5 to 4.5	3.5 to 4.3	3.5 to 4.3
	Magnesium	0.02 to 0.10	0.03 to 0.08	0.03 to 0.08
	Iron max.	0.100	0.100	0.100
	Lead max.	0.007	0.007	0.007
	Cadmium max.	0.005	0.005	0.005
	Tin max.	0.005	0.005	0.005
	Zinc (99.99+percent purity)	Remainder	Remainder	Remainder
Mechanical properties	Charpy impact strength, ft. lb., ¼x¼-in. bar, as cast	20	20	20
	Charpy impact strength, ft. lb., ¼x¼-in. bar, after 8 yr. indoor aging	2	25	19
	Tensile strength, lb. per sq. in., as cast	47,900	40,300	45,400
	Tensile strength, lb. per sq. in., after 8 years indoor aging	49,400	34,400	37,200
	Elongation, percent in 2 in., as cast	5	5	3
	Elongation, percent in 2 in., after 8 years indoor aging	2	8	5
	Expansion (growth) in. per in., after 8 years indoor aging	0.0016	0.0001	0.0001
Other properties and constants (as cast)	Brinell hardness	83	74	79
	Compression strength, lb. per sq. in.	93,100	60,500	87,300
	Electrical conductivity, Mhos./cm. cube at 20 deg. C.	146,000	157,000	153,000
	Melting point, deg. C.	379.5	380.9	380.6
	Melting point, deg. F.	715.1	717.6	717.1
	Modulus of rupture, lb. per sq. in.	116,000	95,000	105,000
	Shearing strength, lb. per sq. in.	45,800	30,900	38,400
	Solidification point, deg. C.	379.3	380.6	380.4
	Solidification point, deg. F.	714.7	717.1	716.7
	Solidification shrinkage., in. per ft.	0.15	0.14	0.14
	Specific gravity	6.7	6.6	6.7
	Specific heat, cal./gm./deg. C.	0.10	0.10	0.10
	Thermal conductivity, cal./sec./cm. cube/deg. C.	0.25	0.27	0.26
	Thermal expansion per deg. C.	27.7×10^{-6}	27.4×10^{-6}	27.4×10^{-6}
	Thermal expansion per deg. F.	15.4×10^{-6}	15.2×10^{-6}	15.2×10^{-6}
	Transverse deflection, in.	0.22	0.27	0.16
	Weight, lb. per cu. in.	0.24	0.24	0.24

step requires spectrographic analysis.

All zinc alloys are subject to slight contraction subsequent to casting, followed by a slight expansion over a long period. These changes, for standard alloys are so slight, however, they rarely need be considered by the designer and, when significant, can be hastened by a stabilizing heat-treatment. These changes are accompanied by some changes in physical properties but these too are only of slight significance in the two zinc alloys most widely used. They are significant for the Zamak-2 alloy, containing 3 percent copper.

Zinc alloys are subject to some cold flow or creep, at atmospheric temperatures, but this rarely need be considered unless high bending stresses are involved. Impact strength, which is high for a cast metal at normal room temperatures, decreases considerably at low temperatures, though even then it is above that for most die-casting alloys. Millions of zinc alloy die-castings are used yearly on automobiles operated under low temperatures. However, breakage of these castings is rare.

Zinc alloys are not recommended for use in contact with steam and are subject to the formation of white corrosion products when in contact with water. Such corrosion can be minimized by simple chemical treatment and is substantially eliminated by common finishes of proper thickness.

Zinc alloys cost less per pound than aluminum alloys but the lower density of the latter, and also of magnesium alloys, may make the cost per unit of volume sometimes favor the lighter alloys. On the other hand, it usually costs more to die-cast aluminum and magnesium.

Aluminum alloys make excellent die-castings and can be cast, as a rule, in shapes and sizes substantially duplicating those for zinc alloys. Strength, except in impact, is not far below that for the zinc alloys and is adequate for a wide range of parts. Light weight is a pronounced asset in most applications of aluminum alloys, and has always been the most important single factor favoring their use. Alloys containing nickel take a brilliant polish and hold it in ordinary atmospheres for long periods even without an applied protective finish. Resistance of aluminum alloys to corrosion is generally high depending on the character of exposure and, to some extent, on the particular alloy chosen. Some alloys machine readily. Others, especially those high in silicon, are more difficult to machine.

Aluminum alloys die-cast at 1,100 to 1,300 deg. F. or at about 400 deg. higher than zinc alloys. This permits the use of aluminum alloys for parts that will be subjected to temperatures higher than permissible for the zinc alloy parts but is a marked disadvantage with respect to die life and casting costs. Casting is slower and more expensive than for the zinc alloys, though costing less than for the copper alloys. Although aluminum die-castings can be plated, plating is not widely done and is considered more difficult than for the zinc alloys. However, aluminum alloys of some compositions are readily anodized and the anodized coatings can be dyed in attractive and brilliant colors. Organic coatings are easily applied, possess excellent adherence, and can be baked at high temperatures. Dimensional changes subsequent to casting are understood to be nil.

Table IV gives the composition and properties of the more important aluminum alloys. Die-casters generally select the alloy best suited for casting the size and shape of the part to be made unless some special requirement demands the use of some one of the other aluminum alloys.

Magnesium alloy die-castings are

confined exclusively to applications in which minimum weight is desired or is essential. Their mechanical properties are about the same as those of aluminum alloys, but casting necessitates certain precautions against fire hazards and can be done only with special furnace equipment and in cold chamber machines. Machining properties of magnesium alloys are good, but machining requires precautions against ignition of chips.

Surface corrosion resistance is generally considered poor, and nearly all castings produced are given a treatment designed to inhibit corrosion and to serve as a base for applied finishes. Though plating has been done, it is only just emerging as a commercial process. Casting is done at about the same temperature as for aluminum alloys and the same dies may be used. Table II gives the properties and composition of the most generally used magnesium alloys for die-casting.

Copper base alloys generally referred to as "brass," are cast at the highest temperatures of any alloys for die-casting and are cast only in cold chamber machines. The high casting temperature is hard on dies. Even the heat-resisting die steels have only moderate life and necessitate rather frequent redressing, if smooth castings are demanded. In addition, copper base alloys are commonly higher in cost than most other types. It is possible, however, to produce copper-base die-castings having tensile strength of about 65,000 lb. per sq. in., or well above that for other die-casting alloys. Compositions and properties of copper-base die-casting alloys are given in Table V. High hardness and high impact strength are also attained and corrosion resistance is superior to that for most other alloys. Uses are confined almost entirely to applications in which these properties are essential.

Choice of Alloys by Designer

In general, the designer chooses that type of alloy which posseses the properties needed and, at the same time, yields the lowest overall cost consistent with these requirements. Cost considerations include the cost per casting as produced, ease and extent of machining, cost of finishing, die cost and die life. Table VI can be used for ready reference when making comparisons. In general, it is best to allow the die-caster to make the choice of the specific type of alloy of a given base metal unless there are important reasons for specifying a particular alloy. When, however, there are standard specifications covering the type of alloy chosen, such specifications should be followed and corresponding checks should be made unless the departure from standard is based upon valid reasons, and a guarantee of satisfactory performance is definitely assured.

Porosity

Die-castings, in common with all other types of castings, are seldom, if ever, completely free from porosity. There may even be voids of considerable size just as "blow holes" often occur in sand castings. This is partly the reason for the common practice of allowing larger factors of safety in cast parts than are allowed in similar

TABLE IV—Composition and Properties of Aluminum for Die-Casting

Composition corresponds with ASTM specifications for ASTM alloys — others as given by Aluminum Company of America. Data mainly supplied by Aluminum Company of America.

Designation									
ASTM	IV	V	VI	VII	VIII	IX	XI	XII	—
SAE	304	305	—	307	—	309	—	312	—
Aluminum Co. of Am. (Alcoa)	43	13	83	85	—	93	—	81	218
Composition, percent									
Copper — for IX, XI, XII, 11 percent max	0.6 max.	0.6 max.	1.5 to 2.5	3.5 to 4.5	1.0 to 2.0	3.5 to 4.5	1.0 to 3.0	6.0 to 8.0	—
Silicon — for IX, XI, XII, 11 percent max	4.5 to 6.0	11.0 to 13.0	2.5 to 3.5	4.5 to 5.5	0.5 to 1.0	1.0 to 2.5	7.0 to 9.0	3.5 max.	—
Nickel — for IX, 11 percent max	0.5 max.	0.5 max.	0.5 max.	0.5 max.	1.75 to 2.5	3.5 to 4.5	0.5 max.	0.5 max.	—
Aluminum	rem.	rem.	rem.	rem.	rem.	rem.	rem.	rem.	rem.
Iron max.	2.0	2.0	2.5	2.3	2.0	1.8	2.0	2.3	—
Zinc max.	0.5	0.5	0.8	1.0	0.5	0.8	0.5	1.8	—
Manganese max.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	—
Magnesium	0.10 max.	0.10 max.	0.10 max.	0.10 max.	0.10 max.	0.05 max.	0.10 max.	0.10 max.	7.5 to 8.5
Tin max.	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	—
Total other impurities max.	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2
Properties and Constants									
Yield strength, tension, (set 0.2 per cent) lb. per sq. in.	13,000	18,000	14,000	19,000	—	20,000	—	24,000	23,000
Ultimate tensile strength, lb. per sq. in.	29,000	33,000	30,000	35,000	29,000	33,000	32,000	32,000	38,000
Elongation, percent in 2 in.	3.5	1.5	3.5	2.7	4.0	1.0	1.7	1.3	5.0
Charpy impact, ft. lb. ¼x¼ in. unnotched specimen	4.5	2.0	5.0	2.5	4.5	2.0	3.0	3.0	10.0
Brinell hardness no.	60	80	60	70	60	80	—	70	—
Specific gravity	2.70	2.66	2.75	2.78	2.72	2.87	—	2.85	2.53
Weight, lb. per cu. in.	0.097	0.096	0.099	0.101	0.098	0.104	—	0.103	0.091
Shearing strength, lb. per sq. in.	18,000	22,000	19,000	22,000	18,000	22,000	—	26,000	—
Melting point (liquid temp), deg. F.	1,165	1,080	1,180	1,145	1,195	1,160	—	1,165	1,160
Thermal conductivity, CGS units	0.38	0.33	0.28	0.27	0.26	0.25	—	0.27	0.24
Thermal expansion, in./in./deg. C.	0.000022	0.000020	0.000023	0.000021	0.000022	0.000021	—	0.000022	0.000024
Electrical resistivity, microhm.-cm	4.2	5.9	5.7	6.2	6.0	6.6	—	6.2	—

Table V—Composition and Properties of Copper Alloys for Die-Casting

Common Name of Alloy	Yellow Brass	Doler Brass No. 1	Doler Brass No. 4 "Brastil"	Doler Brass No. 5	Titan Tinicosil	Manganese Bronze
SAE designation within SAE tolerances as to composition	43	—	—	—	—	43
Composition, percent						
Copper	57–59	65.0	81.5	83.0	42.0	55–60
Zinc	40–42	Rem.	Rem.	Rem.	41.0	38–42
Tin	1.5 max.	0.25 max.	0.10 max.	0.25 max.	—	1.5 max.
Aluminum	0.1 max.	0.05 max.	0.05 max.	1.0	—	1.5 max.
Lead	0.40 max.	0.25 max.	0.25 max.	0.25 max.	1.0	0.40 max.
Manganese	0.0–0.25	0.25 max.	0.25 max.	1.0	—	3.5 max.
Nickel	—	0.25 max.	0.25 max.	0.25 max.	16.0	—
Silicon	—	1.0	4.0	5.0	—	—
Iron	2.0 max.	0.25 max.	0.15 max.	0.25 max.	—	2.0 max.
Other impurities	—	0.25 max.	0.25 max.	0.25 max.	—	—
Properties and Constants						
Ultimate tensile strength, lb. per sq. in.	65,000	65,000	85,000	105,000	85,000	65,000
Yield point, lb. per sq. in.	40,000	35,000	50,000	60,000	65,000–72,000	30,000
Impact strength charpy, ft. lb.	33	36	36	30	—	36
Elongation, percent in 2 in.	15.0	25.0	8.00	5.0	15.0	10.0
Reduction of area, percent	15–20	—	10–15	—	10–18	—
Brinell hardness no.	120–130	120	170	190	160	110–130
Specific gravity	8.5	8.6	8.3	8.2	8.5	—
Weight per cu. in.	0.305	0.308	0.297	0.295	0.305	—
Melting point, deg. F.	1,650	1,575	1,575	1,564	1,675	1,650
Solidification shrinkage, in. per ft.	3/16	—	3/16	—	3/16	—
Machinability	Fair	Good	Fair	Fair	Good	Fair
Corrosion resistance	Good	Good	High	High	High	Good

Table VI—Die-Casting Comparator

Selection Factor	Aluminum Alloys ASTM Nos. 5, 7, 12	Copper Alloys (Brass)	Magnesium Alloys ASTM Nos. 12 and 13	Zinc Alloys ASTM Nos. 21, 23, 25
Mechanical Properties				
Tensile strength	3	1 (strongest)	3	2
Impact strength	3	1 (toughest)	3	2
Elongation	4	1 (most ductile)	3	2
Dimensional stability	2	1 (most stable)	3	3
Resistance to cold flow	2	1 (most resistant)	2	3
Brinell hardness	3	1 (hardest)	3	2
Physical Constants				
Electrical conductivity	1 (highest)	2	3	2
Thermal conductivity	1 (highest)	2	4	3
Melting point	2	3 (highest)	2	1 (lowest)
Weight, per cu. in.	2	4	1 (lightest)	3
Casting Characteristics				
Ease, speed of casting	2	3	2	1 (easiest)
Maximum feasible size	1	2	1	1
Complexity of shape	1	2	1	1
Dimensional accuracy	2	3	2	1 (most accurate)
Minimum section thickness	2	3	2	1 (thinnest)
Surface smoothness	2	3	2	1 (smoothest)
Cost				
Die cost	2	3	2	1 (lowest)
Production cost	2	3	2	1 (lowest)
Machining cost	2	3	1	1
Finishing cost, including polishing and buffing	3	2	3	1 (lowest)
Cost per piece	2	3	2	1 (lowest)
Extent of Use	2	4	3	1 (most used)

parts made from wrought metals. Porosity or voids in die-castings are often caused by trapped air. Proper gating and venting of the die reduces porosity and voids to a minimum, and largely confines them to areas in which stresses are low and strength is ample. Die design is largely empirical. Changes in gating and venting to minimize porosity are often made after the die is built. This is largely a problem for the die-caster, but he should be specifically informed as to where porosity has to be minimized.

There is some evidence that high injection pressures tend to reduce or even substantially to eliminate porosity, but expense may be increased without any corresponding gain by using a pressure higher than good practice has shown to be essential. This matter is commonly left to the die-caster, for the designer of the casting is concerned chiefly with the results secured, rather than with the methods or equipment by which they are attained.

Types of Keys and Keyways Their Relative Merits

ARTHUR H. KORN
Chief Engineer, Holly Pneumatic Systems, Inc.

Information to enable a designer to make a judicious selection of the most efficient key and keyway for a given job, is presented, plus a comparison of the merits and disadvantages of the various keys and keyways. Data are included on the relative methods by which keyways can be cut by various methods.

THE purpose of a key is to transmit a tangential driving force from shaft to hub, or hub to shaft. This produces shearing stresses in the key which, however, may be disregarded because probably nobody ever has seen a key sheared straight through. The compressive stresses to which the sides of the keyway are subjected, are usually calculated on the assumption of uniform pressure over the entire area. This is definitely untrue. The examination of a keyway which has been in service for some time will reveal a deformation as shown in Fig. 1 indicating that the edges have been carrying the load.

The conventional parallel key usually fits closely sideways, and has considerable clearance in the radial direction. The tangential force it transmits sets up a moment or torque which causes a slight turning of the key. This creates reactions at the corners of the key of such magnitude as to counteract the turning moment. As long as no deformation occurs, there is only point contact between key and keyway, and consequently the unit pressure between the two parts, theoretically would be infinite. Actually, however, the unit pressure can rise only to a magnitude at which the material begins to creep, or at which permanent deformations take place. As shown in Fig. 2(*a*), the corners slightly flatten off under this maximum unit pressure the material will stand. The horizontal forces shown, as well as their moments, are then in equilibrium.

If the material of the hub is much softer than that of the shaft, or if the key has a closer fit in the shaft than in the hub, conditions as shown in Fig. 2(*b*) will prevail. It will be clear from this that the total force acting on the flattened keyway portion cannot be transmitted to the hub, part of it is used to counterbalance the reaction at the opposite corner of the key. At best only ⅓ of the depth of keyway could be utilized to transmit the tangential driving force under these circumstances. Hence the mean permissible, compressive stress, taken over the entire keyway depth, should be less than ⅓ of the stress at which permanent deformations begin to develop. This is less than ⅓ of the elastic limit of the material.

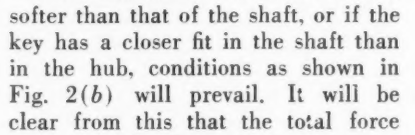


Fig. 1—Keyway deformation of this type reveals that the edges were carrying the load

In case the key has a close fit in the radial direction and clearance sideways, the forces shown in Fig. 2(*c*) and their turning moments will be in equilibrium. Under these conditions theoretically it would be possible to utilize the full depth of keyway to transmit the tangential driving force, provided the key is at least as wide as it is deep, and is fitting tightly.

These considerations reveal the peculiar fact that key and keyways always are subjected to the maximum compression stress the material will stand, no matter how small the load. Depending on the magnitude of the force transmitted, a larger or smaller portion of the keyway area will carry the load. Clarification regarding the forces acting on a key furthermore enables a comparison between keys of square and rectangular sections. In Fig. 2(*a*) and Fig. 2(*b*) obviously the width of the key, is irrelevant. It could be made as narrow as the shearing stresses would permit. There is no good reason therefore to depart from the commonest key, the one of square section.

The standard keys of square and

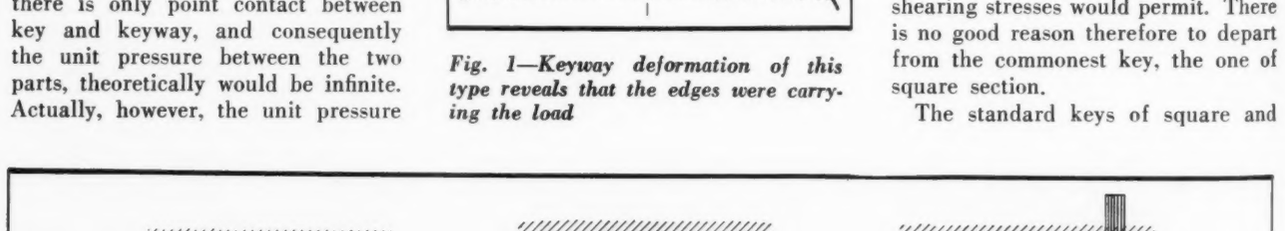


Fig. 2—(a) Tangential force sets up torque which causes a slight turning of the key. (b)Condition where the key has a closer fit in the shaft than in the hub. (c) Where the key has a close fit in the radial direction, and has side clearance

rectangular section for a given shaft diameter have equal width, while the depth (height) of the flat key is about one-half the one of the square key. Since a key fitting tightly in the radial direction can carry a much greater load, the standard flat key can easily be made to carry as much load as the standard square key which has play in the radial direction.

Before cold drawn shafting and ground stock came into general use, and turned parts as a rule were by no means as accurate as today, tight fits of mating parts were preferably obtained by the use of tapers. With a tapered key it was possible to secure tightly, even a wheel with excessive play to a poorly finished shaft. To facilitate withdrawal, the key was provided with a nose and in that form is known as the draw- or gib-key. The projecting nose proved a great safety hazard, for loose garments had a way of getting caught by the key. Safety regulations were issued which called for "key guards."

This key, which has become almost extinct in major industries, was supposed to be fitted to the tapered keyway of the hub. This was not always understood for every now and then, a tapered key was found driven into straight keyways. A piece of cold drawn stock requiring no machining at all has taken its place. The transition occurred so quietly that technical writers never became aware of it, and as a result, current engineering literature still holds the gib-key to its former glory.

The tapered key does something no other key can do. It secures against great lateral thrust. Wherever the lateral thrust is so great that it is not advisable to rely on set screws, and where at the same time press fits or even shrink fits are not desired because the wheel has to be readily removed, and where clamping of the wheel by means of a split hub is not feasible, use of the draw-key still can be justified.

A key in the ascendancy is the Woodruff key, Fig. 3. It is widely used in the machine tool and automotive industries. Just why a particular key should prove superior in some fields and fail to gain wide acceptance otherwise is a perplexing phenomenon. A machine designer will not be satisfied with a mere statement of facts. If he is to make a judicious selection, he must know the underlying reasons for this trend. At first glance the key may appear complicated, a departure from a cold drawn stock key to that of a machined shape, with a change from a straight keyway to a semi-circular one. However, this is the most inexpensive key and the cutting of the slot is mere child's play compared with that of other keyways. Because of mass production, the key itself is very cheap.

Dimensions and tolerances of key, keyslot and keyslot cutter have been standardized, so that a standard key will readily give the desired fit in a slot produced by a standard cutter.

Woodruff keyslot standards do not establish the depth of slot but the limits of the dimension from bottom of slot to the opposite side of the shaft $H_{min.}$ and $H_{max.}$ illustrated in Fig. 4. If the shaft diameter varies between $D_{min.}$ and $D_{max.}$ the depth of slot is given by

$$T_{min.} = D_{max.} - H_{max.}$$
$$T_{max.} = D_{min.} - H_{min.}$$

This applies to the usual case in which the tolerance on the shaft diameter is less than the one of dimension H.

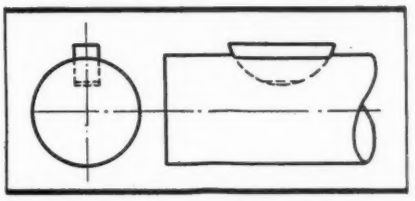


Fig. 3—Woodruff keyway is easy to produce

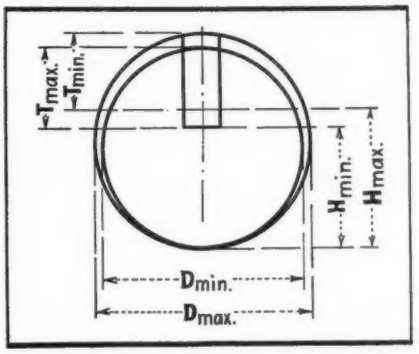


Fig. 4—Dimension limits for Woodruff keyslot cutting procedure requires depth of slot

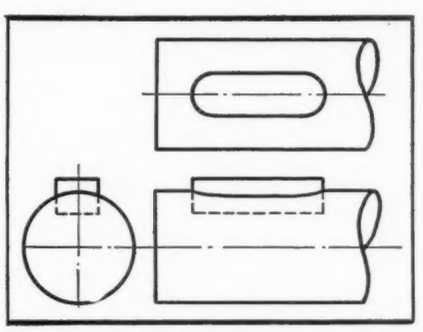


Fig. 5—Keyway milled with an end mill secures the key against lateral movement

Cutters to Minimize Fillet on Parallel Keyways

Width of Keyway in.	Shaft dia. in.	Milling Cutter: Min. dia. Woodruff key slot cutter	Milling Cutter: Preferable dia. side cutter
1/8	1/2 to 9/16	1/2	
3/16	5/8 to 7/8	1/2	
1/4	15/16 to 1-1/4	5/8	
5/16	1-5/16 to 1-3/8	3/4	3
3/8	1-7/16 to 1-3/4	7/8	4
1/2	1-13/16 to 2-1/4	1	4
5/8	2-5/16 to 2-3/4	1-1/4	5
3/4	2-7/8 to 3-1/4		6
7/8	3-3/8 to 3-3/4		6
1	3-7/8 to 4-1/2		7
1-1/4	4-3/4 to 5-1/2		8
1-1/2	5-3/4 to 6		8

Cutting a parallel keyway is by no means as simple. The small sizes, 1/4 in. wide and less have to be cut with a Woodruff cutter as the only one available. The larger sizes are better cut with a side cutter. Neither one can cut the correct width of slot in a single operation. Standard widths of parallel keyways are such that specially selected cold drawn stock can be used as a key. The actual stock size is larger than nominal measurements. Tolerances for standard parallel keys are narrower than that for cold drawn stock. On the standard side cutter, however, the tolerance is unfortunately positive.

A considerable portion of the parallel keyway is useless on account of the curved bottom or fillet which the cutter produces at the end. This can be kept down to a minimum by using smallest diameter Woodruff cutters as given in the table. Better results are obtained, and heavier cuts can be taken with side cutters.

The curved bottom of the end of a keyway produced by a side cutter can be annoying in that it is difficult to keep the key in the parallel part of the keyway when the wheel is pressed on the shaft. A keyway milled with an end mill has a straight bottom and secures the key against lateral movement, Fig. 5. This, however, is the most expensive keyway. An end mill can take heavy cuts when fed in the axial direction. When milling a keyway, however, it has to be moved laterally and then the cutting section is little better than scraping. A good way to mill this keyway, especially the larger sizes, is by roughing it out with a side mill and finishing it up with an end mill.

Industry and Societies

NEWS · READER LETTERS · MEETINGS

Statistics Indicate Huge Amount of Engineering in Modern Airplanes

How much engineering, measured in time and number of drawings, goes into a modern airplane was indicated by statistics recently released by the Glenn L. Martin Company. Taking as an example the Martin Marauder, known in the army as the B-26 medium bomber, it was pointed out that by the end of 1942 there had been 19,036 drawings made for this plane. If these drawings and the blueprints made from them were all one-foot wide and placed end to end, they would be 580 mi. long and 51,450 lb. in weight.

Before the first B-26 was delivered 485,000 man hours of engineering were required, and an additional 440,000 hours have since been added in making changes suggested by combat experience. The original engineering was done in eight months. Another example is the Martin Mariner patrol bomber which took 1,300,000 man hours of engineering before the first plane was delivered to the Navy.

To facilitate reproduction of these drawings, a process of photo reproduction by means of which the drawings are copied on negatives and then projected on sensitized metal, paper, cloth or wood has been developed in the Martin plant. A special camera, the largest in the world, and occupying two rooms, had to be built. The projected drawings can be made to size, smaller or larger, as required. This process is now available to the aircraft industry and has helped a great deal in speeding up plane production.

There are now about 2,200 people on the engineering staff of the Martin company. These people put in 422,099 man-hours of engineering per month.

Official Photograph, U. S. Army Air Forces

Thin stainless-steel sheets have replaced aluminum in many of the inclosures around the engines and for such parts as the cowling, shroud, and exhaust collector of the Ford bomber. Original specifications called for 16-gage aluminum, which is approximately 0.051 in. thick and weighs 0.694 lb. per sq. ft. For this, 26-gage stainless steel, 0.018 in. thick and weighing 0.75 lb. per sq. ft., was substituted. Before changing to steel an attempt was made to produce these aluminum parts in dies, using heat-treated stock, but the resulting scrap loss on some parts ran over 60 percent. Even though the 26-gage steel is paper thin, loss in dies has been reduced to nearly zero. Results indicate that the substitution is advantageous if the parts are inclosures and do not support loads.

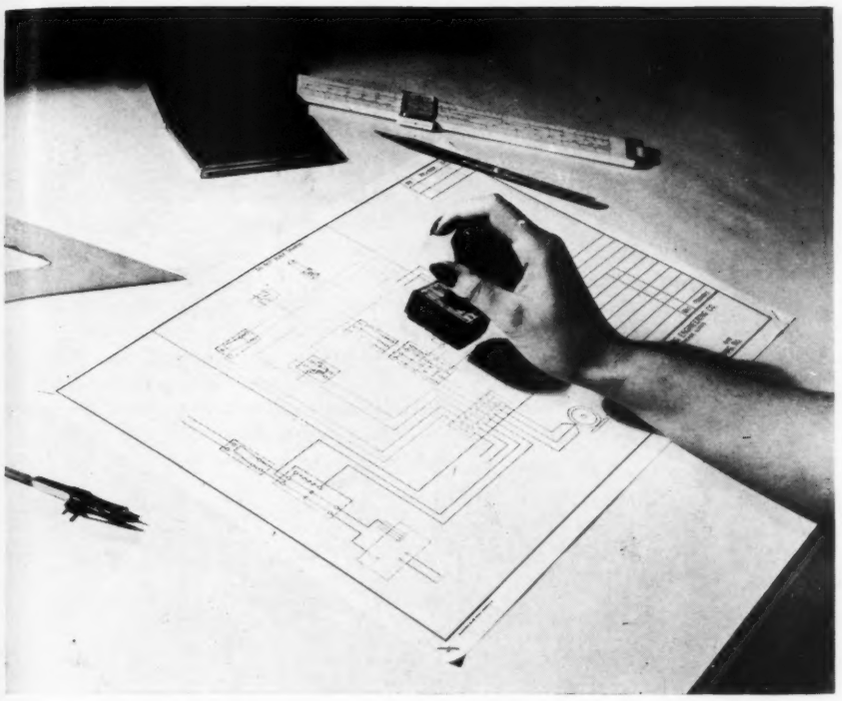
New Adhesive Protects Plastics for Aircraft

Transparent inclosures for military aircraft will flow to assembly lines without interruption because of a new adhesive developed by the Plastic Department of E. I. du Pont de Nemours & Company. Large quantities of crude rubber also will be saved by the use of this new adhesive.

Protection of the plastic inclosures during transportation from manufacturing point to assembly line is necessary to preserve the highly polished surfaces of the plastic. The masking paper used for this protection in the past has been fastened to the surface of the plastic with rubber cement. However, because of the critical shortage of crude rubber, development of a less critical substitute was undertaken at the request of the War Production Board, Army and Navy. More than 100 different adhesives were tested during the year-long search for this substitute.

Primarily, the adhesive must keep the protecting paper fastened to the plastic through all handling, shipping, fabricating and assembly. The paper is not stripped off until the plane is ready for its initial flight. It must withstand extremes of temperature and humidity. The paper must strip off easily, but not self strip and can leave no deposit.

The new Du Pont adhesive actually stands up better in sunlight than rubber cement and does not "crack off"



Symbols for switches, pipes, valves, and similar standard pieces of equipment used in the engineering department of the Lindberg Engineering Company have been made into rubber stamps which are being used on engineering drawings. One of the big advantages is the time saved. For instance, a portion of a wiring diagram for a furnace used for hardening aircraft parts requires approximately eight hours of drawing time. The use of rubber stamps has cut this time to three hours. Other advantages are greater accuracy and a greater degree of uniformity between various drawings and between the same symbols on a single drawing. A great deal of time also has been saved in training female replacements for men inducted into military service. The highest price paid for a rubber stamp so far is $7.50 and it is estimated that enough time was saved in man-hours to pay for this stamp in the making of a single drawing.

from the plastic. It does not age as fast as rubber adhesive and is more uniform in quality. This new adhesive is applied to paper by the same equipment previously used for rubber cement. It has a petroleum base and is dispersed in various chemicals to form the product.

Captured Weapons Show Axis Has Critical Materials

GERMANY AND ITALY do not lack critical materials for war weapons, judging from analyses of captured equipment which has been brought to this country. Information and data as to particulars are not yet available, but indications of the material supply situation in the Axis countries are becoming more frequent.

Aluminum has been used almost lavishly in the manufacture of some of these captured items. There are some places where aluminum is used as structural material, whereas the Allied Nations use steel. Brass and copper appear in Axis equipment abundantly. In fact, brass, mica, alloys and other strategic materials are used where less critical items might do the job.

There are indications, too, that Germany is adding new chemicals to gasoline to produce 130 octane fuel at a nominal cost. Sources of these additives are ample on the continent.

How the Axis nations obtain the materials is not readily apparent. It should be kept in mind, however, that the civilian economy under war conditions of the whole continent of Europe is much more restricted than that of the United States. This, combined with extreme regimentation of labor and production capacity, could easily make for a more effective use of whatever materials are available, even though the supply may be much less in quantity than the supplies of the corresponding materials for the United Nations.

Property Custodian Want Alien Patents Used

EFFORTS ARE BEING MADE to have United States patents controlled by enemy aliens, and now held by the Alien Property Custodian, used to the advantage of the United Nations. A statement of policy, titled "Patents at Work," explains the procedure for obtaining rights to the patents and includes an index to the classified lists for use as a guide in ordering patents in specific sections.

All such patents are now being abstracted and listed in a form for easy reference and study. Abstracts and further information, including copies of the statement of policy, may be had by contacting the Alien Property Custodian at any of the following addresses: 120 Broadway, New York, N. Y.; National Press Building, Washington, D. C.; Field Building, Chicago, Ill.; 315 Montgomery St., San Francisco, Calif.

Rivets strong enough to replace bolts on aircraft or other structures are being used by North American Aviation, Inc. Nearly 1,000 of the new rivets, which can be installed five times faster than bolts, are used in the wing of the P-51 Mustang fighter plane, replacing a large number of regular rivets and 798 heavier bolts. Two or more regular rivets are required to equal the strength of one Hi-shear rivet, as the new fastening is called. It has a shear strength of 75,000 lb. per sq. in. Use of the new rivets saves 60 percent in weight over former bolts and rivets. A special tool that presses a small aluminum collar into the notched end of the stud, leaving a modified conical head, makes possible the use of such a hard rivet. The tool and rivet were developed by George Wing, a North American engineer.

General Electric Company

Improvements in the design of X-ray equipment for diffraction studies have been brought about by substituting a window of beryllium for one of Lindemann glass. Non-porous beryllium, necessary for the requirements of X-ray tube service, is prepared by an electrolytic process by the Brush Beryllium Company. Vacuum-tight disks, which are sealed into the wall of the tube, are made by a vacuum melting process. Much of the work of preparing these disks has been done in the General Electric Research Laboratory. Each disk is soldered to a ring of iron-nickel alloy and this is fastened to hard glass. This, in turn, has made possible the construction of a smaller and more efficient tube than previous types. The new tube can even be immersed in an oil tank containing the high-voltage transformer, and the apparatus made portable. The X-ray transparency of beryllium, considerably greater than that of Lindemann glass, and the improved design have increased by 15 times the speed with which diffraction patterns are obtained and has lengthened the service life of tubes. This is believed to be the first commercial use of pure beryllium. In the illustration the beryllium window is held at the right and the pencil indicates the opening in the tube where the window fits.

Discussions and Comments from Readers

SWIMMING DOG PROBLEM SOLVED

EDITOR'S NOTE: The swimming dog problem, published in December PRODUCT ENGINEERING, has been solved by three readers by similar methods. The shortest and most direct of these three solutions is outlined below, omitting the details of integrations, which may be checked by reference to integral tables. Credit goes to Mr. Zinman, whose solution is given, and to J. Bromberg, both of whom are engineers for the Board of Water Supply, New York City. Their solutions were worked out independently of each other.

The third solution was submitted by W. P. Michell, executive engineer, Mack Manufacturing Corporation, Allentown, Pa. The variation in his solution is also shown.

We do not know whether or not the problem of the swimming dog has any practical applications. However, the following are possible applications. If an airplane pilot flying in a cross wind by radio beam between two points kept the nose of his plane pointed in the direction of this destination, his path would be similar to that of the dog and his time would be longer than if he headed slightly into the wind.

Assuming the invention of a torpedo that could be automatically controlled and directed toward a moving enemy warship target by some force, the determination of its path involves solution of a similar problem in which the water is still and the man moving along the bank of the river at a speed less than the dog's swimming speed, as assumed by Mr. Michell below.

To the Editor:

The path of the dog swimming to his master across the river is shown by the accompanying curve. From the geometry of the figure, using polar coordinates, it is obvious that the absolute velocity R of the dog at any time is made up the vector sum of two velocities: 2 m.p.h. and the river flow rate k m.p.h. This velocity may be broken up into two velocities such that one is along the radius vector ρ and one perpendicular to it. These velocities are $\frac{d\rho}{dt}$ and $\rho\frac{d\theta}{dt}$ respectively

$$\text{where } t = \frac{a}{2} \times \frac{1}{12} \text{ (hr.)}$$

$$\text{Then } \frac{d\theta}{dt} = -(2 - k \sin\theta)$$

$$\text{and } \frac{\rho d\theta}{dt} = k \cos\theta$$

These two differential equations may be solved simultaneously thus:

$$dt = \frac{d\rho}{-(2 - k\sin\theta)} = \frac{\rho d\theta}{k\cos\theta}$$

Therefore

$$\frac{d\rho}{k\sin\theta - 2} = \frac{\rho d\theta}{k\cos\theta}$$

Separating variables:

$$\frac{d\rho}{\rho} = \frac{(k\sin\theta - 2)\,d\theta}{k\cos\theta}$$

$$= \left(\tan\theta - \frac{2}{k}\sec\theta\right)d\theta$$

$$\log\rho = -\log\cos\theta - \frac{2}{k}\cdot\frac{1}{2}\log\left(\frac{1+\sin\theta}{1-\sin\theta}\right) + \log c$$

See Pierce, Short Table of Integrals

When $\theta = O$, $\rho = a$ (See sketch)

Therefore $\log a = \log c$ and $a = c$

$$\rho = \frac{a}{\cos\theta\left(\frac{1+\sin\theta}{1-\sin\theta}\right)1/k} \qquad (1)$$

At the point (ρ_1, θ_1) the dog stops moving downstream and his upstream component of velocity equals k, the rate of flow of the river. At this point then:

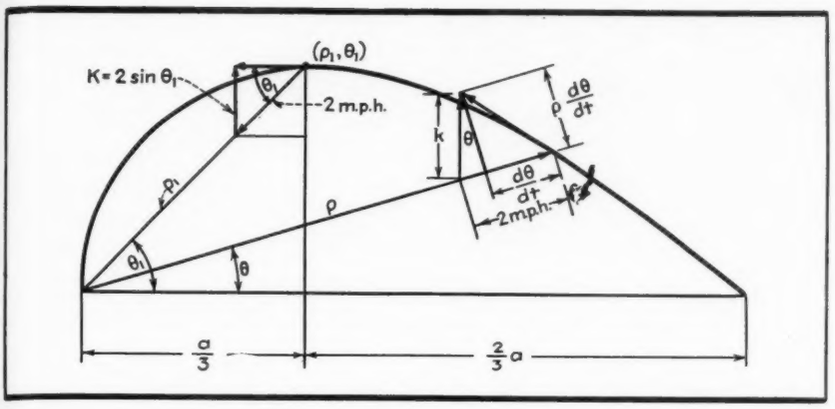
$$k = 2\sin\theta_1 \text{ and } \rho_1 = \frac{a}{3\cos\theta_1}$$

Substituting for $\sin\theta$ and ρ in Equation (1) at (ρ_1, θ_1)

$$\frac{a}{3\cos\theta_1} = \frac{a}{\cos\theta_1\left(\frac{1+0.5\,k}{1-0.5\,k}\right)^{1/k}}$$

$$\text{Therefore } 3 = \left(\frac{1+0.5\,k}{1-0.5\,k}\right)^{1/k}$$

A simple way to determine k is to plot k against the function of k and thus locate the point where the curve of the function equals 3. However, it is immediately obvious that the equa-



tion is satisfied when k=1. Equation 1 then becomes:

$$\rho = \frac{a(1-\sin\theta)}{\cos\theta(1+\sin\theta)} \times \frac{1+\sin\theta}{1+\sin\theta}$$

$$= \frac{a\cos^2\theta}{\cos(1+\sin\theta)^2} = \frac{a\cos\theta}{(1+\sin\theta)^2}$$

$$dt = \frac{\rho d\theta}{k\cos\theta} = \frac{a\cos\theta\, d\theta}{\cos\theta(1+\sin\theta)^2}$$

$$= \frac{a\, d\theta}{(1+\sin\theta)^2}$$

$$t = \int_0^{\frac{\pi}{2}} \frac{a\, d\theta}{(1+\sin\theta)^2}$$

$$= a\left[\frac{\tan\theta/2}{3(1+\cos\theta)} + \frac{1}{3}\tan\frac{\theta}{2}\right]_0^{\pi/2}$$

$$t = \frac{a}{3}(2) = \frac{2}{3}a$$

But the problem states $t = \frac{a}{2} + \frac{1}{12}$

$$\frac{2}{3}a = \frac{a}{2} + \frac{1}{12}$$

Therefore, by reducing to a common denominator:

$8a = 1 + 6a$

$a = \frac{1}{2}$ mile = width of the river

$t = \frac{1}{12} + \frac{1}{4}$ hr. = 20 minutes

—Samuel C. Zinman
Board of Water Supply, New York City

With k known, to find width a set up rectangular coordinates with the dog at the origin and the man at the point $x=a$, $y=0$. The man now travels on the line $x=a$ at the stream velocity while the dog follows a "pursuit curve" assumed through still water. The equation of the pursuit curve, using a factor N equal to the ratio of dog swimming speed to stream velocity, is:

$$2y = \frac{N a^{\frac{1}{N}}(a-x)^{\frac{N-1}{N}}}{1-N} + \frac{N a^{-\frac{1}{N}}(a-x)^{\frac{N+1}{N}}}{1+N} - \frac{2Na}{1-N^2}$$

Substituting $N=2$,

$$2y = -2\sqrt{a(a-x)} + \frac{2}{3}\frac{(a-x)^{3/2}}{\sqrt{a}} + \frac{4}{3}a$$

When $x = a$ $\quad y = \left(\frac{a}{2} + \frac{1}{12}\right)1$

Therefore $2\left(\frac{a}{2} + \frac{1}{12}\right) = \frac{4}{3}a$

$$a = \frac{1}{2}$$

—W. P. Michell
Mack Manufacturing Corporation

TABLES OF SPRING TOLERANCES HAVE INCORRECT HEADINGS

In Tables I, II and III of the article, "Commercial Tolerances for Springs," by Harold Carlson, chief engineer, Lee Spring Company, which appeared on pages 156 and 157 of Product Engineering for March, the subheadings under "Spring Index" are given as "Up to 7 (small), 7 to 11 (average)" and in Table I "11 to 13 (large)." These subheadings are incorrect and in all three tables should read "Up to 6 (small), 6 to 10 (average), 10 to 12 (large)." The second word of Note 3 under Table III should be "values" instead of "valves."

STRESS CONCENTRATION FACTORS

Abstract of article II on "Stress Concentration Factors" by George H. Neugebauer, March Product Engineering, p. 168, states incorrectly that fatigue is not a factor in the first 31 cases covered in Part I in February. Actually the distinction is between methods of determining the factors. The first 31 factors were determined by theoretical methods while those in March were determined by fatigue tests. The last sentence should read, "Seven cases are added to the 31 given last month, which were determined by various theoretical methods and are shown to be limiting values for fatigue tests."

In Case XXXIV, Table II, p. 170, and Case XXXVII, Table VI, the first k should be k_t. In the equation, column 1, the first equals sign should be a plus sign.

ORDNANCE OFFICER PRAISES CIRCULAR ON REDESIGN BUSINESS

To the Editor:

This office has received a copy of your circular, "How to Do Redesign Business with Uncle Sam." We believe that it is the most objective and clearcut statement of the Conservation Program, and the ways in which it can be assisted, that has appeared to date. Instructions given are concise and the "sales talk" is temperate and effective.

Would it be possible to have you furnish this office with additional copies for distribution—say 500?

—W. A. Morey
1st Lt., Ord. Dept.
Chicago Ordnance District

Meetings

Electrochemical Society — Spring meeting, April 7-10. Hotel Roosevelt, Pittsburgh, Pa.

National Electrical Manufacturers Association—Spring meeting, April 20-23. Palmer House, Chicago, Ill.

American Society of Mechanical Engineers—Spring meeting, April 26-28. Hotel Black Hawk, Davenport, Iowa.

American Foundrymen's Association—47th annual meeting, April 28-30. Hotels Jefferson and Statler, St. Louis, Mo.

American Society of Mechanical Engineers — Semi-annual meeting, June 14-16. Hotel Biltmore, Los Angeles, Calif.

American Society for Testing Materials—Annual meeting, week beginning June 28. Hotel William Penn, Pittsburgh, Pa.

Do You Know That—

There are 1,000 applications of plastics in a modern battleship. (13)

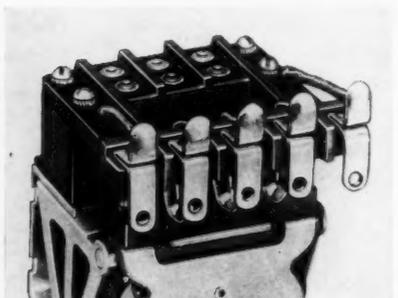
Rubber mountings for the isolation and insulation of vibration, shock and noise are now being made of synthetic rubber. (14)

Glass cloth, darkened with a colloidal graphite finish is going into shades of parachute flares used in bombing operations, because the glass cloth is light in weight and can withstand the intense heat of the flare. (15)

New Materials and Parts

Relay Designed Especially For Aircraft Use

Designed particularly for aircraft use is the G-M 3PDT Type 27 relay, which has characteristics that may point to its use in other applications. Size of No. 12814, typical of this type, is 2 x 1⅞ x 2⅛ in., and the weight is 5 oz. Acceleration is 15 G+; 12 volts d.c. nominal coil voltage; 6.5 volts (0.92 watts) pick-up at 20 deg. C.; 3.2 watts coil wattage at 12 volts d.c.;



60 grams contact pressure; 10 amperes contact capacity at 30 volts d.c.; and 32 deg. C. temperature rise at 12 volts d.c. G-M Laboratories, 4326 N. Knox Ave., Chicago, Ill.

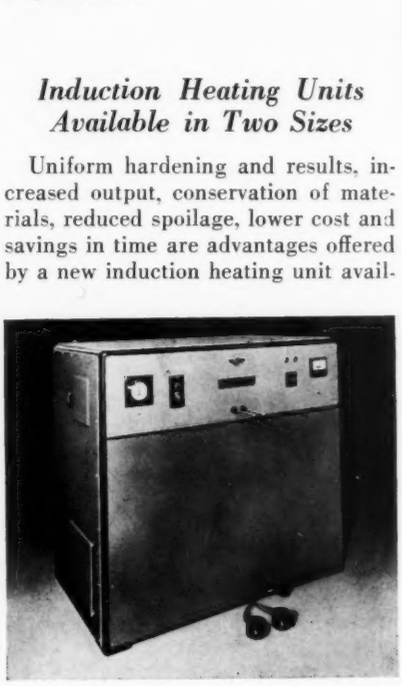
Rotary Pump Has Improved Removable Liner

Construction which allows removal of a worn-out liner is a feature of a new rotary pump. The unit operates on the same swinging-vane principle

as other pumps in the company's line. The replacement operation involves only the removal of the pump heads, driving out the old liner, and inserting a new one. Self-adjusting buckets eliminate fitting. The anchoring mechanism is simplified, the cam bore changed and the intake and discharge "streamlined" to handle more viscous liquids and increase the volumetric efficiency of the pump. The units with improved removable liner are made in capacities from 20 to 750 gal. per min., and pressures up to 300 lb. per sq.in. Blackmer Pump Co., Grand Rapids, Mich.

Induction Heating Units Available in Two Sizes

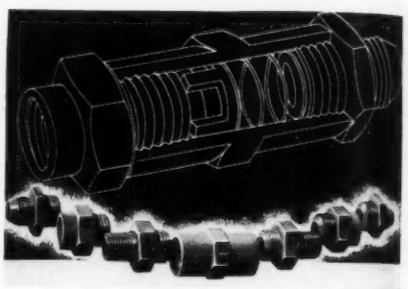
Uniform hardening and results, increased output, conservation of materials, reduced spoilage, lower cost and savings in time are advantages offered by a new induction heating unit avail-



able in 16 kw. and 32 kw. sizes. Each machine is an inclosed unit which may be adapted for hardening and heating of parts made in small lots or incorporated in a production line. To operate, the proper heating coil for a particular job is connected and the heat and quench cycle required are set. To change from one job to another the work-holding fixture, heating coil and heating cycle are changed to meet the new requirements. The entire operation is automatic. Van Norman Machine Tool Co., Springfield, Mass.

Universal Check Valve Has Twelve Combinations

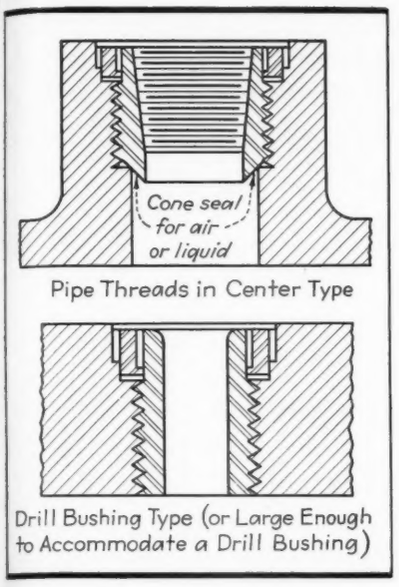
Twelve combinations can be made with one body and any two of three types of adapters with the new ASP check valve designed primarily for aircraft hydraulic lines. A phenolic poppet seats at either end of the valve body. Adapters are available for flared



tubing for external and internal pipe threads. The standard body is made in all standard tubing sizes of heat-treated aluminum alloy. No breakdown or distortion has been shown in tests up to 50,000 reciprocations at temperatures up to 275 deg. F. American Screw Products, Los Angeles, Calif.

Locking System for Threaded Inserts and Studs

By means of a simple ring with serrations inside and out, designed by Jose Rosan, studs can now be locked into place as a simple procedure. Essentially the use of this locking system consists of the following steps: Drill, counterbore, and tap the material. A bolt, a lock nut and a hammer are the only mechanical aids required. For increasing the efficiency of the process, a threaded tool and lock nut have been developed to install the insert into the material using the wrench on the nut, until the nut contacts the surface of the material. Loosen the nut and remove the tool from the insert. Locate the locking ring on top of the insert. Drive the ring into position with the drive tool, using a hammer or press. To remove the insert, the operator drills


Cone seal for air or liquid
Pipe Threads in Center Type
Drill Bushing Type (or Large Enough to Accommodate a Drill Bushing)

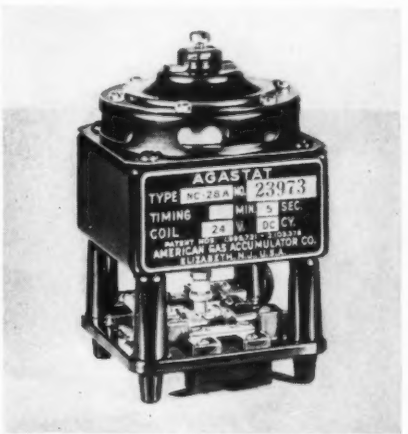
to a depth equal to that of the serrations between the ring and the insert. Bardell & McAlister. Inc., Hollywood, Calif.

Portable Coolant Pump Can Be Permanently Installed

Compact design enables installation in a small space of a self-contained portable coolant pump unit, designated Model 16-S. The unit can be installed as permanent equipment or moved from one machine to another. Coolant flow can be regulated. The motor is rated at 1/30 hp., 1,525 r.p.m., air jacketed, fan-cooled, operation on 110 volts, 60 cycle, single-phase current. The pump is a centrifugal type. Tank size is 16 x 10 x 9 in., and the height of the motor above the tank is 4¾ in. Weight of the unit is 40 lb. The tank is made of 16-gage steel. The pump is cast iron and is so designed that there is no metal-to-metal contact below the liquid level. Maximum pressure is 4½ lb. per sq.in., and maximum capacity is 3¾ gal. per min. Eastern Engineering Co., 45 Fox St., New Haven, Conn.

Redesigned Relay Has Wide Operating Range

In redesigning the electro-pneumatic time delay relay known as Agastat, efficiency was increased, more available materials were used and the size with respect to displaced area was decreased. The new unit has a single-screw adjustment which permits a delay ranging from a fraction of a second to several minutes. The number of moving parts has been decreased to essentials. The basic design and principle of operation incorporated in the former model have been incorporated in the redesign. The new unit is 1 lb., 6 oz. lighter, and the height is 1 in. shorter. American Gas Accumulator Co., Elizabeth, N. J.

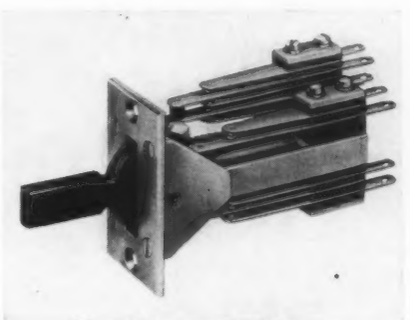


Phenolic Resins Developed For Specific Purposes

Two new phenolic molding materials have been developed for handling specific molding problems. The first, CM-13017, is designed especially for production of aircraft and automotive ignition parts. The material is natural in color and is especially suitable for extrusion molding around inserts. Among the physical properties of the molded material are specific gravity, 1.86; modulus of elasticity, 10 x 10^5 lb. per sq.in.; impact strength, per inch of notch, 0.30 ft. lb.; flexural strength, 9.500 lb. per sq. in.; and mold shrinkage, 0.002–0.0035 in. per in. Electrical properties of the molded material include dielectric strength at 60 cycles, instantaneous, 350 volts per mil; power factor at 1,000 cycles, 0.06; dielectric constant at 1,000 cycles, 6.0, and volume resistivity, 6 x 10^5 megohms cm. The material known as CM-16034 was developed for long flow extrusion work and is also suitable for transfer molding. Physical properties of the molded material include specific gravity, 1.36–1.40; modulus of elasticity, 8 x 10^5 lb. per sq.in.; impact strength, per inch of notch, 0.30 ft. lb.; flexural strength, 10.000 lb. per sq.in.; and mold shrinkage, 0.008–0.01 in. per in. Electrical properties of the molded material include dielectric strength at 60 cycles, instantaneous, 325 volts per mil; power factor at 1,000 cycles, 0.13; dielectric constant at 1,000 cycles, 7; and volume resistivity, 1.7 x 10^5. Neither of the compounds is recommended for use where molded parts are to be subjected to temperatures greater than 300 deg. F. Bakelite Corp., 30 E. 42nd St., New York, N. Y.

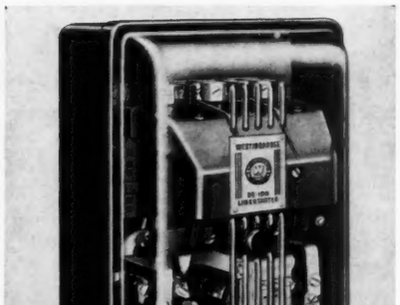
Lever Switch Has Many Combinations

Numerous series of combinations of contact assemblies are available with the 0-42 lever switch, designed primarily for use in aircraft, radio, communications, annunciator and fire-alarm systems. Contacts, pile-ups and lever action are assembled to meet specific requirements. Positive action, light weight and no throw stops are features. Recommended maximum rate is 5 amp. at 110 volts a.c., non-inductive. Donald P. Mossman, Inc., 6133 N. Northwest Highway, Chicago, Ill.



Linestarter Requires Less Mounting Space

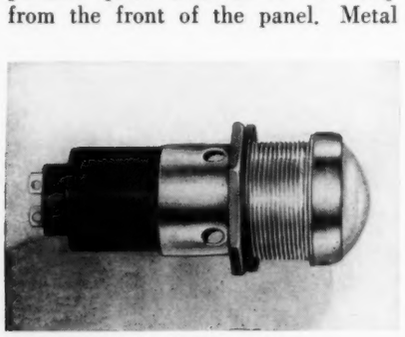
For such equipment as machine tools, textile machinery, pumps and fans, a new Size 2 Glass 11-200 linestarter requires less than half the mounting space of former units without sacrificing wiring space. The



switch is designed for group mountings, built-in applications or remote mountings. It has a new clapper-type armature with knife edge. Double break silver-to-silver contacts are utilized, eliminating shunts and reducing maintenance. Overload relays are reset either by hand or automatically. For applications requiring sequence or auxiliary interlocking, provision is made for a total of four normally open or normally closed electrical interlocks. All parts are accessible from the front and all control-circuit and interlock terminals are clearly marked for easy installation and repair. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

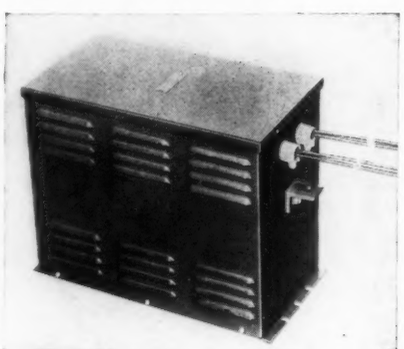
Pilot Light Has Heavy-Duty Construction

Features of the new No. 675 pilot light are heavy-duty construction and double-contact, candelabra, bayonet socket housed in a fixed black phenol plastic base. The unit, designed for horizontal mounting in panels up to ½-in. thick, has a one-inch jewel. Smooth, colorless, frosted-back glass jewels, with removable color disks, or diamond-cut colored glass, are optional. Amber, blue, green, red, white and yellow colors are available. The slip-fit bezel, which holds the jewel, permits quick removal of the lamp from the front of the panel. Metal parts are cadmium plated, except the bezel which has a polished chrome finish. Any double contact, candelabra-sized, bayonet-base lamp with C-7, G-6, S-6, or T-4½ size bulb can be used. Drake Mfg. Co., Chicago, Ill.



Load Power Factor Does Not Affect Stabilizer

Constant output of 115 volts from circuits varying between 95 and 130 volts are provided with a voltage stabilizer which is not sensitive to load power factor. The unit is not affected by variations in load from no load to full load, or by changes in power factor from unity to 0.8 lagging. It is self-protecting and it will operate continuously throughout the range from open circuit to short circuit without change. Ratings range from 50 volt-amperes to 5,000 volt-amperes. Applications include radio transmitters, electron tube apparatus, motion picture sound equipment and projectors, telephone apparatus, X-ray machines, and in the calibration of meters, instruments and relays. General Electric Co., Schenectady, N. Y.



High Shear Strength Rivet Saves Weight

Hard rivets with a shear strength of 75,000 lb. per sq.in. are now being used in aircraft structures to replace bolts. Use of the new rivets has effected a 60 percent weight reduction in relation to the equivalent bolts and rivets previously used. Secret of the rivet, named Hi-shear, is a special tool which presses a small aluminum alloy collar into the notched end of the stud, leaving a modified conical head. The excess length of the collar is sheared off automatically during installation by pressure of the tool against the sharp edge on the tip of the stud. Used in parts subject to shear loads, where bolts previously were necessary, the rivets come in two styles of heads, in several diameters and in lengths to suit all conditions. Two or more regular rivets are required to equal the strength of one Hi-shear rivet. The rivet and tool were developed by an engineer for an aircraft company which is not in the rivet manufacturing business. However, they are being made available to other war materiel manufacturers. North American Aviation, Inc., Inglewood, Calif.

Stitching Wire Fastens Dissimilar Materials

Rubber, plastics, fiber board, laminated wood and other construction materials can be fastened to stainless steel or aluminum by stitching or binding with a new type wire. Stitches can be made at the rate of several hundred per minute. Wire is of a special analysis. It has a tensile strength of 290,000 lb. per sq. in., a zinc coating and withstands a salt spray for several hundred hours. Very little tolerance from the required 0.051 in. diameter is permitted. The wire will penetrate stainless steel 0.03 in. thick, duralumin 0.04 in. thick or aluminum 0.06 in. thick. Other softer materials can be penetrated to a thickness of ¾ in. At the present time much of this wire is being used for production of various sub-assemblies of war planes. American Steel and Wire Co., Cleveland, Ohio.

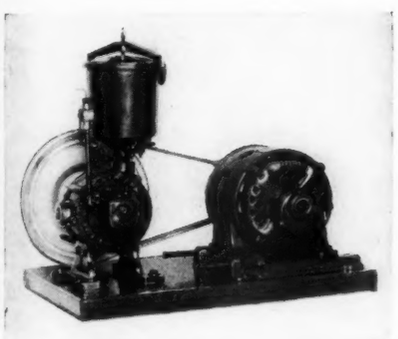
Angle Brackets Have Self-Contained Fasteners

Developed to speed up assembly and reduce weight in aircraft and other war equipment, a line of six angle brackets with self-contained fasteners for non-structural attachments features an integrally formed Speed-Nut in one or both sides of the bracket, according to need. The brackets are made for 8Z and 10Z Air Corps sheet metal screws and standard rivets. They are made of special aircraft spring steel, black coated and finished with zinc chro-

mate primer. When used in connection with conduit or tubing the bracket also permits the use of standard bonding clamps in place of ear-type aluminum bonding clamps. Tinnerman Products Inc., 2041 Fulton Road, Cleveland, Ohio.

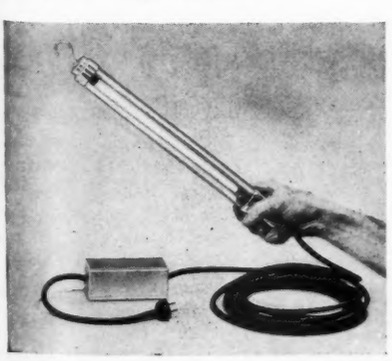
Vacuum or Pressure Created For Testing by Pump

Delicate instruments, such as those used on aircraft, which must be accurately adjusted can be tested with a motor-driven rotary pump which produces either vacuum or pressure. One of the important features of this pump is that it automatically compensates for wear on moving parts. Both the vacuum and the pressure can be adjusted. Automatic controls and lubrication are provided. Leiman Bros. Inc., Newark, N. J.



Inspection Light Has Fluorescent Lamp

Safety features of Lucite are combined with the long tubular shapes characteristic of fluorescent lamps in a recently introduced fluorescent inspection light. A combination metal baffle and support shields the light from the inspector's eyes. Construction is sturdy and simple. A standard cord plug and ballast box with 20 ft. of cord are part of the equipment which comes with the light. Commercial Reflector & Mfg. Co., 3109 Maple Ave., Los Angeles, Calif.



Manufacturers' Publications

SHEET METAL — American Rolling Mill Co., Middletown, Ohio. Booklet, 24 pages. New information on Armco Zincgrip and helpful suggestions for specifying, ordering, fabricating and finishing this special zinc-coated sheet metal are given. Physical properties, deep drawing, roll forming, brake forming, welding, cleaning and recoating welded joints, soldering and finishing are covered.

CONTROL PANELS—Vickers, Inc., 1400 Oakman Blvd., Detroit, Mich. Bulletin 41-40, 16 pages. Features of "traverse and feed cycle" control panels for drilling, reaming, boring, turning, milling and swaging machinery are explained with tables, circuit diagrams and installation drawings.

CHAINS AND SPROCKETS — Diamond Chain & Manufacturing Co., Indianapolis, Ind. Catalog 643, 32 pages. Complete information, including principles, on the selection, installation and maintenance of precision roller type chains and sprockets for aircraft use are included.

WELDING AND BRAZING — Aluminum Company of America, Pittsburgh, Pa. Booklet, 100 pages. This is a rewritten edition of the company's previous welding booklet, bringing it up to date and including a discussion of the art of brazing aluminum.

MANGANESE STEEL—American Manganese Steel Div., American Brake Shoe & Foundry Co., 389 E. 14th St., Chicago Heights, Ill. Bulletin 1142-5M, 48 pages. Besides describing how the use of manganese steel helps to offset impact and abrasion on steel mill equipment, the booklet discusses the properties and composition of this material.

FRACTIONAL-HORSEPOWER MOTORS—Dumore Co., Racine, Wis. Bulletin 120, 24 pages. Actual-size photographs, dimensional drawings, specifications, ratings, applications and performance of company's standard and special aircraft motors ranging from 1/50 to ¼ hp., feature this catalog.

DRAWING BOARD SURFACE — W. H. Long Co., 425 N. Clark St., Chicago, Ill. Folder, 4 pages. Describes the drawing board top known as No-Ink, which has been restyled to meet war plant conditions.

CASTINGS—Hamilton Foundry & Machine Co., 1551 Lincoln Ave., Hamilton, Ohio. Bulletin 1, 32 pages. About 200 gray iron and Meehanite castings made by the company are described and illustrated in this bulletin, which also commemorates the 50th anniversary of the company.

PLATING—Crowell-Collier Publishing Co., 250 Park Ave., New York, N. Y. Brochure, 16 pages. Special process of chrome plating and treating the edge of cutting tools, increasing life 100 to 1,000 percent before grinding is necessary, is described. Process was developed by Axel Lundbye, company's chief engineer, and was first used in printing plant.

DISTRIBUTION DUCT—BullDog Electric Products Co., 7610 Joseph Campau Ave., Detroit, Mich. Bulletin 427, 76 pages. Contains descriptions and illustrations of basic design, methods of estimating and layouts, symbols for layout men and estimators, suggested hanger arrangements, technical information and construction details, application data, typical specifications and similar information on the enclosed busbar method of electrical distribution.

COMPRESSORS AND VACUUM PUMPS—Allis-Chalmers Manufacturing Co., Milwaukee, Wis. Bulletin B-6211, 20 pages. Complete engineering description of Ro-Flo compressors and vacuum pumps of the sliding-vane type is supplemented by installation diagrams, photographs, section views and curves showing the relationship between pressure, temperature and volume.

BLIND RIVETS—Cherry Rivet Co., Los Angeles, Calif. Handbook, 16 pages. Charts, diagrams, dimensional sketches and photographs present a clear picture of how these rivets are used for airframe construction, repair and salvage. Complete information is given on the Cherry riveting process together with detailed instructions on the operation and care of tools.

ALUMINUM BRONZE — Ampco Metal, Inc., Milwaukee, Wis. Engineering Data 110, 1 page. Specifications are given for metals of the type made by Ampco and covered in Aeronautical Material Specification Nos. 4630A, 4632 and 4640.

Books and Bulletins

Process Practices in the Aircraft Industry

FRANK D. KLEIN, JR.—266 *pages, 6x9 in. Blue clothboard covers. Published by McGraw-Hill Book Co., 330 West 42nd St. New York, N. Y. Price* $2.75.

A timely and instructive book covering the various processes, methods, and materials employed in the aircraft industry. The separate sections and chapters of the volume are arranged in accordance with the sequence of production flow, so that the reader can follow the airplane or part from the point at which raw stock is received to the final acceptance of the part.

The subject matter presented is grouped into five main divisions, which embrace characteristic raw materials, metals in production, fabrics and compositions, process materials, and standard process methods. The chapters on procurement methods, aluminum and its alloys, magnesium and its alloys, steel, fabrics, organic finishes, and inspection methods should be of special interest to design engineers.

Comprehensive tabular data and detailed schedules distributed throughout the text make the book a valuable reference manual.

Tool Design

CYRIL DONALDSON and GEORGE H. LECAIN—443 *pages, 6x9 in. Black clothboard covers. Published by Harper and Brothers, 49 East 33rd St., New York, N. Y. Price* $3.75.

One of the Rochester Technical series of textbooks. Content is selected primarily for persons who are preparing themselves to fill the position of tool designer, however, estimators, planning experts and production engineers should find the book to be a help in solving many technical problems associated with tooling.

Chapters which are of especial interest to design engineers are: manufacturing processes as they affect the designer, properties of materials, tolerances and allowances, springs, welding, punch and die design, and cam design. Other subjects covered that concern the work of the tool designer more intimately are cutting tools, gages, jigs and fixtures, construction of the Brown and Sharpe automatic screw machine and its accessory tools, and turret lathes. Numerous half tones and line drawings accompany the text.

The book sets forth the general methods of tool design in a comprehensive manner and should enable any technical worker to develop ideas into practical specifications for the production of parts by modern manufacturing methods.

Industrial Inspection Methods

LENO C. MICHELON—389 *pages, 8x10¾ in. Blue clothboard covers. Published by Harper and Brothers, 49 East 33rd St., New York, N. Y. Price* $3.50.

Aim and purpose of this book is to explain and to illustrate the correct use and application of tools and measuring instruments used in industry to maintain exactness in dimensions of manufactured products. It was prepared in response to the present urgent demand for textbooks that can be used to train instructors, who in turn will teach junior inspectors in the objectives and technique of securing quality control in the production of interchangeable parts.

Included in the subjects discussed are: Characteristics of quality control; all the conventional gages, tools and methods employed in non-precision and in precision dimensional control; gears and their inspection; comparator and electro-limit gaging; optical measuring instruments; layout and tool inspection; statistical methods of product sampling; x-ray inspection, and Magnaflux inspection.

Plastics from Farm and Forest

E. F. LOUGEE—157 *pages, illustrated, 5x7 in. Gray clothboard covers. Published by Plastics Industries Technical Institute, Los Angeles, Cal. Price* $2.

Here is easy-to-read background information on present-day plastics and their development. In simple, nontechnical language, the author points out sources of raw materials and the by-products of agriculture and industry which may be turned to profit in this rapidly-expanding field. The book is not written for those who know plastics; it is written for those who know little and want to know more. Consequently, detailed chemical formulas, physical data, technical application information are purposely omitted. As a means of acquainting the general reader with these new materials and their modern uses, the book fills a definite need.

Machine Design

P. H. HYLAND and J. B. KOMMERS—562 *pages, 6x9 in. Blue clothboard covers. Published by McGraw-Hill Book Co., 330 West 42nd St., New York, N. Y. Price* $4.50.

In this third edition the previous arrangement of chapters has been retained, but some of the sectional sub-divisions have been moved around in order to obtain better sequence of subject material. To make space for new material and at the same time not increase the number of pages, many sections have been condensed.

Included in the sections which have been revised and expanded are those covering welding processes, plastics, hardness and strength of materials, factors of safety, bearings and lubrication, belting, riveted joints, screw fastenings and power screws, toothed gearing, springs and columns. New problems and illustrations have been used throughout the book.

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Tests of Joints in Low-Alloy Steels

WILBUR M. WILSON, WALTER H. BRUCKNER and THOMAS H. MCCRACKIN, JR.—76 *pages, 43 illustrations, 19 tables, 6x9 in. Published by the University of Illinois, Urbana, Ill. Price, 80 cents.*

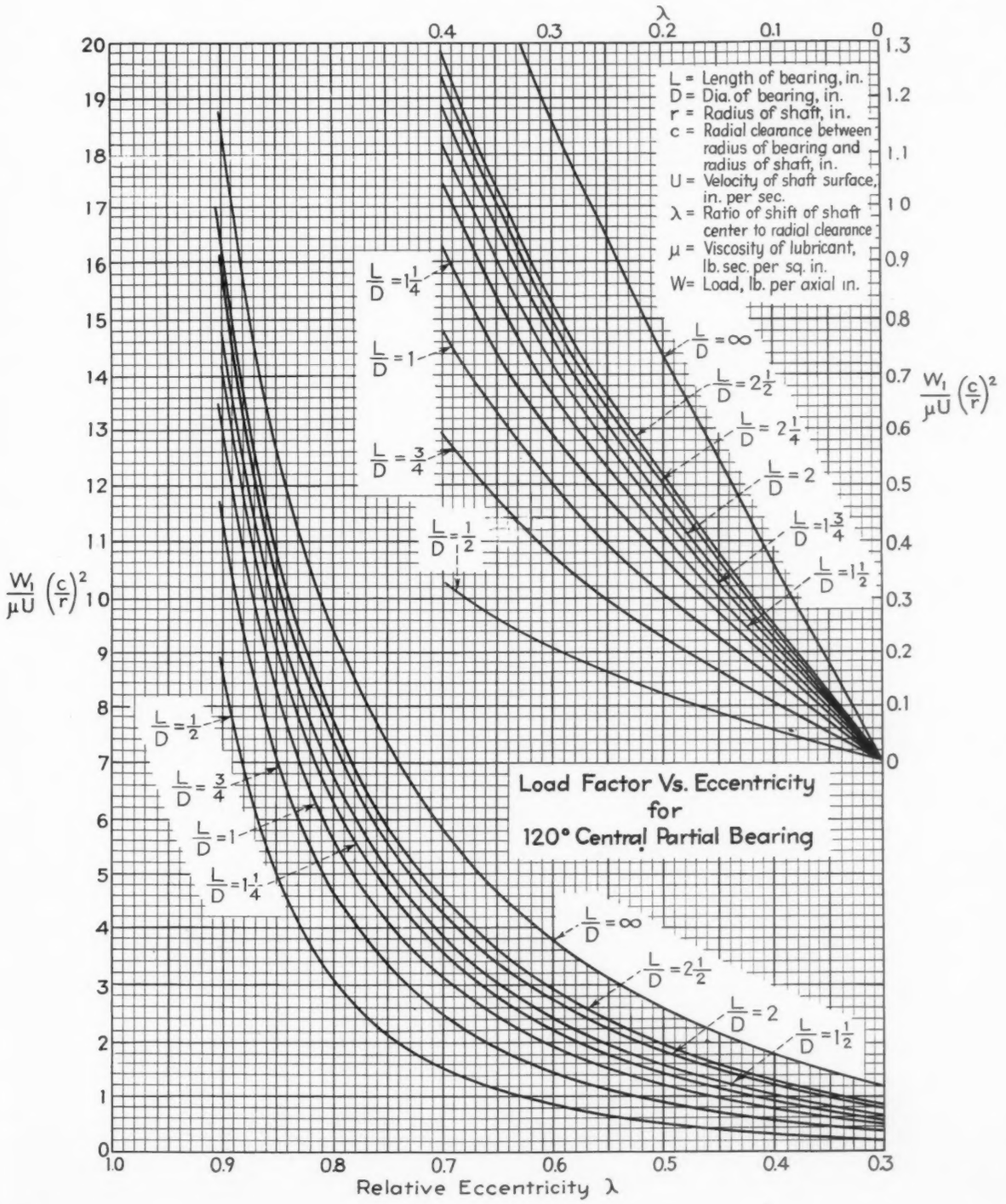
This is Bulletin No. 337, "Tests of Riveted and Welded Joints in Low-Alloy Structural Steels," issued by the Engineering Experiment Station of the University of Illinois. The object of the investigation described was to determine the properties of three low-alloy structural steels, furnished in accordance with A.S.T.M. Specifications A242-41T, and to determine the behavior of structural joints fabricated of these steels. Tests were made to determine the chemical composition and physical properties of the materials; initial tension, tensile strength, hardness and shearing strength of driven rivets; strength of plates without joints, of joints in plates fabricated by riveting and of joints in plates fabricated by welding. Metallurgical studies also were made to determine grain sizes and hardness valves of the rivets, plates and welds.

Bearing Design Data

MERHYLE F. SPOTTS
Northwestern Technological Institute

THESE CHARTS are supplements to the article "Design of Self-Cooled Journal Bearings—I," see page 231. The data plotted below shows the variation of load factor at various eccentricities for 120 deg. central partial bearings of different length diameter ratios.

Variation of tangential friction force at various eccentricities for 120 deg. central partial bearings of different length diameter ratios is plotted and shown on the next page.



Bearing Design Data

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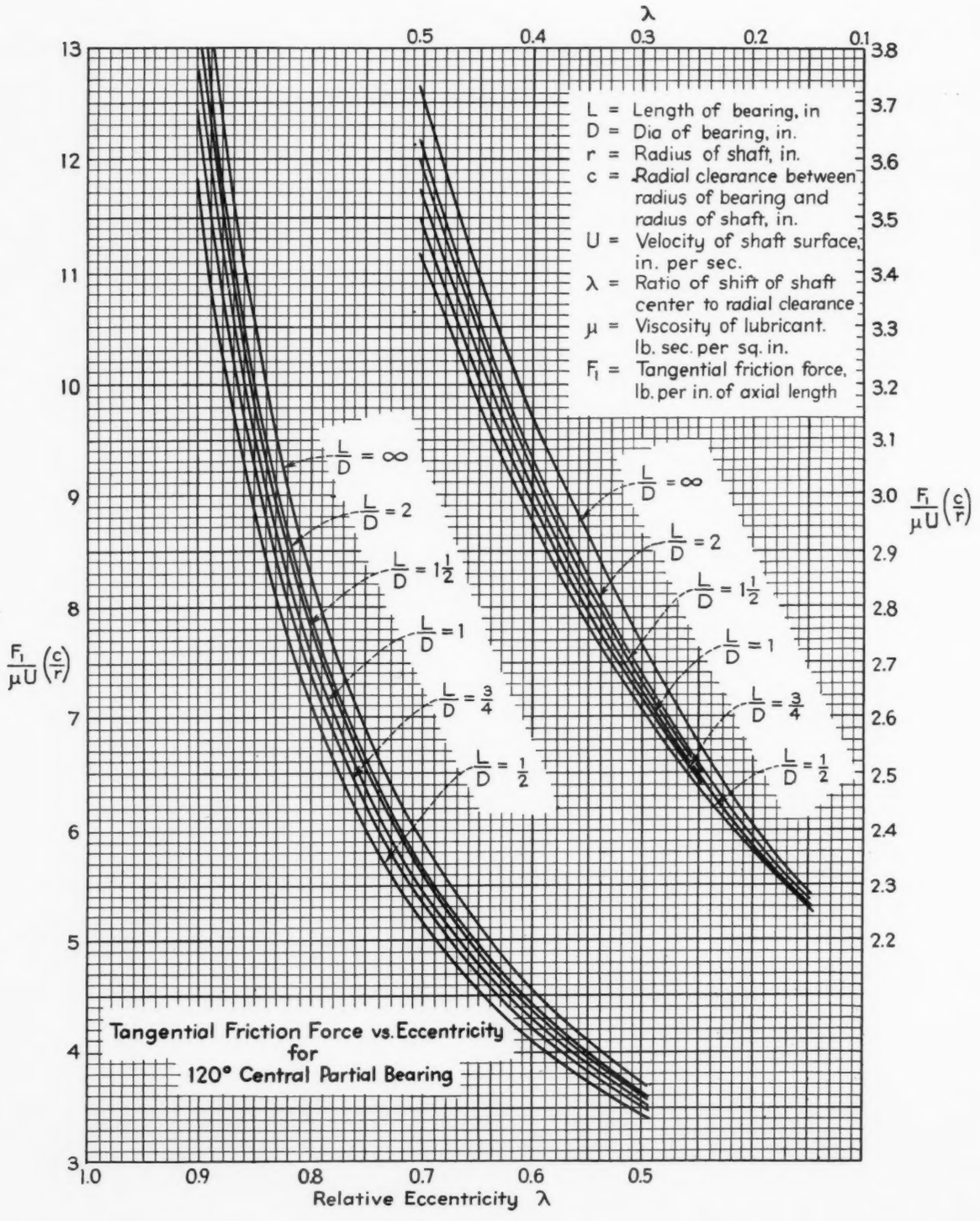
λ
0.5
0.4
0.3
0.2
0.1
L = Length of bearing, in
D = Dia of bearing, in.
r = Radius of shaft, in.
c = Radial clearance between radius of bearing and radius of shaft, in.
U = Velocity of shaft surface, in. per sec.
λ = Ratio of shift of shaft center to radial clearance
μ = Viscosity of lubricant. lb. sec. per sq. in.
F1 = Tangential friction force, lb. per in. of axial length
L/D = ∞
L/D = 2
L/D = 1½
L/D = 1
L/D = ¾
L/D = ½
F1/μU (c/r)
Tangential Friction Force vs. Eccentricity for 120° Central Partial Bearing
Relative Eccentricity λ
1.0
0.9
0.8
0.7
0.6
0.5

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